British Journal of Hospital Medicine

Br. J. Hosp. Med. (Lond) **2026**; 87(9): 58254
https://doi.org/10.31083/BJHM58254

Systematic Review

The Efficacy of Different Exercise Intervention Models and Dosages on Post-Stroke Depression: A Systematic Review and Network Meta-Analysis

Xiaolu Fan[1], Xinyu Dai[2], Quancheng Peng[1], Wei Dai[1], Xiaoqiang Yin[1], Shuai Hou[3,*]

[1]Department of Rehabilitation, The Third People's Hospital of Hubei Province (Zhongshan Hospital), 430000 Wuhan, Hubei, China
[2]Department of Neurology, Traditional Chinese and Western Medicine Hospital of Wuhan, Tongji Medical College, Huazhong University of Science and Technology, 430000 Wuhan, Hubei, China
[3]Department of Rehabilitation, Xianning Central Hospital, 437000 Xianning, Hubei, China
*Correspondence: cdzyydxhs@163.com (Shuai Hou)
Academic Editor: John Alcolado
Submitted: 6 August 2025 Revised: 19 October 2025 Accepted: 30 October 2025 Published: 21 September 2026

Abstract

Aims/Background: Post-stroke depression (PSD) is a prevalent psychological complication among stroke survivors. Exercise intervention, as a non-pharmacological therapeutic approach, plays a crucial role in the rehabilitation of PSD. This study aimed to systematically evaluate the efficacy of various exercise intervention models and exercise doses on PSD through a network meta-analysis. The findings are expected to provide personalized exercise recommendations for patients with PSD and further promote the integration of exercise therapy into stroke rehabilitation. **Methods**: This study was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Relevant randomized controlled trials (RCTs) published up to April 2025 were retrieved from PubMed, Cochrane, Embase, Ovid, and Web of Science databases. Data analysis was performed using R statistical software. **Results**: Exercise interventions lasting less than 8 weeks, performed at least five times per week, and with individual sessions of 30 minutes or less, demonstrated the most significant improvement in PSD symptoms. As the exercise dose increased, the antidepressant effects of mixed aerobic exercise (MAE), combined exercise (CE), resistance training (RT), high-intensity interval training (HIIT), moderate-intensity continuous training (MICT), traditional martial arts (TOMA), and yoga (YOGA) all exhibited a continuous downward trend. Among these, resistance training (RT) showed the most significant decline, with no subsequent rebound effect. **Conclusion**: All exercise intervention models effectively alleviate PSD symptoms, with resistance training emerging as the most effective single exercise modality. However, the optimal exercise dose for resistance training remains to be established. Further clinical studies are warranted to clarify the dose-response relationship and optimize exercise dose PSD management. **Systematic Review Registration**: PROSPERO (CRD420251012962).

Keywords: exercise; stroke; depression; meta-analysis

1. Introduction

Stroke, a common cerebrovascular disease, is characterized by high incidence, high disability rates, and high mortality, making it the second leading cause of death globally [1]. Stroke can adversely affect multiple aspects of a patient's life, including physical, psychological, and cognitive domains [2]. Post-stroke depression (PSD) is one of the most prevalent complications, with approximately one-third of stroke patients developing depression at various stages following the event. Symptoms of PSD include persistent low mood, poor sleep quality, loss of interest, memory impairment, difficulty concentrating, speech inhibition, pessimism, and even suicidal tendencies [3]. PSD not only hinders patients' physical and psychological recovery but also interferes with their reintegration into family and society, ultimately leading to increased disability and mortality rates post-stroke [4].

Currently, the management of post-stroke depression primarily relies on pharmacological and non-pharmacological interventions. Pharmacological treatments, however, are associated with delayed onset, poor adherence, high relapse rates, and prolonged recovery within the optimal treatment window [5]. Previous study has confirmed that exercise is an effective non-pharmacological intervention for alleviating anxiety and depression [6]. As a non-pharmacological therapy, exercise interventions have been demonstrated to significantly improve the physical and psychological well-being of patients with PSD [7].

Various forms of exercise interventions have been shown to effectively alleviate PSD. Aerobic exercises, such as brisk walking, jogging, and cycling, have been reported to effectively reduce depressive symptoms in stroke patients [8]. Progressive resistance training can prevent muscle atrophy, promote post-stroke rehabilitation, enhance quality of life, and contribute to psychological recovery [9]. Research has also shown that flexibility-based exercises, such as yoga, which improve physical flexibility and coordination, exert positive effects on PSD [10]. Moreover, traditional Chinese medicine practices, such as Ba Duan Jin, have been found to effectively reduce neural damage, enhance daily functioning, and improve depressive symptoms and sleep quality among stroke patients [11].

While exercise interventions play a beneficial role in alleviating PSD, the effects of different exercise interventions, as well as the optimal duration, frequency, and intensity of exercise, remain inadequately evaluated. Some studies have suggested that performing moderate- to high-intensity exercise three to five times per week can significantly improve psychological symptoms, while others have reported that one to two sessions of low-intensity exercise per week can also alleviate psychological symptoms to some extent. Additionally, longer exercise durations ($\geq$30 minutes per session) are associated with improved mental health, while shorter durations (e.g., 15 minutes of brisk walking) can also yield mental health benefits. Moreover, high-intensity exercises, such as high-intensity interval training (HIIT), can produce greater improvements in mental health. However, low-intensity exercises, including yoga and walking, can also effectively improve mental state by promoting relaxation and mind-body integration.

The relationship between exercise dose (frequency, duration, and intensity) and its impact on mental health outcomes is complex and remains controversial. Some studies suggest that higher exercise frequency and intensity yield superior benefits, while others indicate that even low-frequency, short-duration, or low-intensity exercises can produce positive effects [12,13,14]. These observations highlight the need to consider individual differences, exercise preferences, and feasibility when designing intervention programs to optimize their efficacy. Therefore, this study aimed to explore the comparative efficacy of various exercise intervention approaches in alleviating post-stroke depression and to identify the optimal exercise dose for achieving the best therapeutic outcomes.

2. Methods

This systematic review and meta-analysis adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [15] and was registered in the PROSPERO database (ID: CRD420251012962, https://www.crd.york.ac.uk/PROSPERO/view/CRD420251012962). The study was reported in accordance with the PRISMA 2020 statement; the completed PRISMA 2020 checklist is provided in the **Supplementary Material**.

2.1 Search Strategy

A comprehensive literature search was conducted in PubMed (https://pubmed.ncbi.nlm.nih.gov), Cochrane Library (https://www.cochrane.org/learn), Embase (https://www.embase.com/landing?status=grey), Ovid (https://ovidsp.ovid.com), and Web of Science (https://clarivate.com/academia-government/scientific-and-academic-research/research-discovery-and-referencing/web-of-science/). The English search terms were: (“Post-stroke depression”) AND (“Exercise”) AND (“Randomized Controlled Trial (Publication Type)”). The following free-text terms were also used without restriction: “Exercises”, “Sports”, “Physical Activity”, “Motor Activity”, “Training”, “Endurance Training”, “Isometric Exercise”, “Acute Exercise”, “Exercise Training”, “Tai Chi”, “Yoga”, “Balance”, “Resistance”, “Flexibility”, “Cardiovascular”, and “Aerobic”. These were supplemented through reference tracing and manual searches (Table 1).

The search covered relevant literature from the database since its inception to April 2025. A combination of MeSH terms and free-text keywords was employed to maximize search sensitivity and specificity.

2.2 Inclusion Criteria

The inclusion criteria for this study were established based on the PICOS (Population, Intervention, Comparison, Outcomes, Study) framework [16]: (1) Population: Individuals diagnosed with depression following a stroke, irrespective of gender, aged 18 years or older, and assessed using standardized depression scales; (2) Interventions: Exercise interventions, including virtual rehabilitation (VR) scenario simulation training, music therapy, comprehensive rehabilitation training, aerobic exercise, high-intensity interval training, resistance training, endurance balance training, Tai Chi, Baduanjin, and yoga. The corresponding intervention frequency and duration were also reported; (3) Comparators: Control groups that did not receive exercise therapy or were subjected to low-intensity or low-frequency exercise interventions; (4) Outcomes: The primary outcome was depression. Most studies employed the Hamilton Depression Rating Scale (HAMD) [17] or the Beck Depression Inventory (BDI) [18]. Other assessment tools included the Geriatric Depression Scale-Short Form (GDS-SF) [19], the Hospital Anxiety and Depression Scale (HADS) [20], the Major Depression Inventory (MDI) [21], the Mental Component Summary (MCS) of the 36-Item Short Form Health Survey (SF-36) [22], and the Patient Health Questionnaire-9 (PHQ-9) [23]. These instruments collectively assess both the physical and psychological dimensions of post-stroke depression; (5) Study: Randomized controlled trials (RCTs).

The following studies were excluded: (1) Duplicate publications; (2) Animal studies, cell-based experiments, and pharmacological research; (3) Reviews, guidelines, case reports, and conference abstracts; (4) Studies with missing data or full text unavailable even after contacting the corresponding authors; (5) Case-control, cross-sectional, and longitudinal studies.

Table 1. Literature search strategy.

Database	Search strategy
PubMed	(post-stroke depression [MeSH Terms] OR post-stroke depression[Title/Abstract]) AND (Exercise[MeSH Terms] OR Exercise[Title/Abstract] OR Exercises[Title/Abstract] OR Sports[Title/Abstract] OR Physical Activity[Title/Abstract] OR Motor Activity[Title/Abstract] OR Training[Title/Abstract] OR endurance training[Title/Abstract] OR Isometric Exercise[Title/Abstract] OR Acute Exercise[Title/Abstract] OR Exercise Training[Title/Abstract] OR Tai Chi[Title/Abstract] OR yoga[Title/Abstract] OR Balance[Title/Abstract] OR Resistance[Title/Abstract] OR Flexibility[Title/Abstract] OR Cardiovascular[Title/Abstract] OR Aerobic[Title/Abstract])
Cochrane	(post-stroke depression):ti,ab,kw AND ("exercise"):ti,ab,kw OR (Exercises):ti,ab,kw OR (Sports):ti,ab,kw OR (physical activity):ti,ab,kw OR (Motor Activity):ti,ab,kw OR (Exercise Training):ti,ab,kw OR ("training"):ti,ab,kw OR (endurance training):ti,ab,kw OR (Isometric Exercise):ti,ab,kw OR (Acute Exercise):ti,ab,kw OR (Tai Chi):ti,ab,kw OR (yoga):ti,ab,kw OR (Balance):ti,ab,kw OR (Resistance):ti,ab,kw OR (Flexibility):ti,ab,kw or (Cardiovascular):ti,ab,kw OR (Aerobic):ti,ab,kw
Embase	'post-stroke depression'/exp OR 'post-stroke depression' OR (('post stroke'/exp OR 'post stroke') AND ('depression'/exp OR depression)) AND 'exercise'/exp OR exercise OR exercises OR 'sports'/exp OR sports OR 'physical activity'/exp OR 'physical activity' OR (physical AND ('activity'/exp OR activity)) OR 'motor activity'/exp OR 'motor activity' OR (('motor'/exp OR motor) AND ('activity'/exp OR activity)) OR 'training'/exp OR training OR 'endurance training'/exp OR 'endurance training' OR (('endurance'/exp OR endurance) AND ('training'/exp OR training)) OR 'isometric exercise'/exp OR 'isometric exercise' OR (isometric AND ('exercise'/exp OR exercise)) OR 'acute exercise'/exp OR 'acute exercise' OR (acute AND ('exercise'/exp OR exercise)) OR 'exercise training'/exp OR 'exercise training' OR (('exercise'/exp OR exercise) AND ('training'/exp OR training)) OR 'tai chi'/exp OR 'tai chi' OR (tai AND chi) OR 'yoga'/exp OR yoga OR 'balance'/exp OR balance OR 'resistance'/exp OR resistance OR 'flexibility'/exp OR flexibility OR cardiovascular OR aerobic
Ovid	post-stroke depression.af. AND (Exercise OR Exercises OR Sports OR Physical Activity OR Motor Activity OR Training OR endurance training OR Isometric Exercise OR Acute Exercise OR Exercise Training OR Tai Chi OR yoga OR Balance OR Resistance OR Flexibility OR Cardiovascular OR Aerobic).af.
Web of Science	TS=(post-stroke depression) AND Preprint Citation Index (Exclude – Database) AND TS=(Exercise)) OR TS=(Exercises)) OR TS=(Sports)) OR TS=(Physical Activity)) OR TS=(Motor Activity)) OR TS=(Training)) OR TS=(endurance training)) OR TS=(Isometric Exercise)) OR TS=(Acute Exercise)) OR TS=(Exercise Training)) OR TS=(Tai Chi)) OR TS=(Yoga)) OR TS=(Balance)) OR TS=(Resistance)) OR TS=(Flexibility)) OR TS=(Cardiovascular) and Preprint Citation Index (Exclude – Database) and Preprint Citation Index (Exclude – Database)

ti, title; kw, keyword; ab, abstract; exp, explode; TS, topic search; af, All Fields; MeSH, Medical Subject Headings.

2.3 Data Synthesis and Analysis

Two independent reviewers (XYD and XLF) screened the retrieved studies according to the established inclusion and exclusion criteria. Disagreements were resolved by a third reviewer (XQY). Extracted data were recorded in Microsoft Excel (Microsoft Office 2021; Microsoft Corporation, Redmond, WA, USA), including the following variables: first author, country, year of publication, sample size, male-to-female ratio, intervention type, intervention duration, frequency, intensity, and outcome assessment scales.

Exercise intervention strategies were categorized into eight groups based on their primary characteristics: CG: control group, CE: combined exercise, RT: resistance training, MAE: mixed aerobic exercise, HIIT: high-intensity interval training, MICT: moderate-intensity continuous training, TOMA: traditional martial arts, YOGA: yoga.

2.4 Methodology for Quantifying Exercise Dose

The metabolic equivalent of task (MET) was used as a standardized index to quantify exercise intensity and energy expenditure. This metric is widely applied in international sports physiology and rehabilitation research, demonstrating high accuracy across diverse populations, including individuals of varying genders, ages, nutritional statuses, and physical fitness levels. In this study, exercise dose was calculated by multiplying the MET value of the activity by the duration of a single session (in minutes) and the number of exercise sessions per week. The MET values for each exercise type were determined according to the 2011 Physical Activity Guidelines [24], which outline standards for exercise intensity, duration, and frequency.

For dose-response network meta-analysis using R 4.1.1 software (R Foundation for Statistical Computing, Vienna, Austria), standard deviation (SD) was derived from the reported standard errors (SEs) and sample sizes using the following formulas:

$$SE = \frac{UL - LL}{2 \times 1.96}$$

$$\mathrm{SD} = \mathrm{SE} \times \sqrt{\mathrm{n}}$$

Where n represents the sample size of each study.

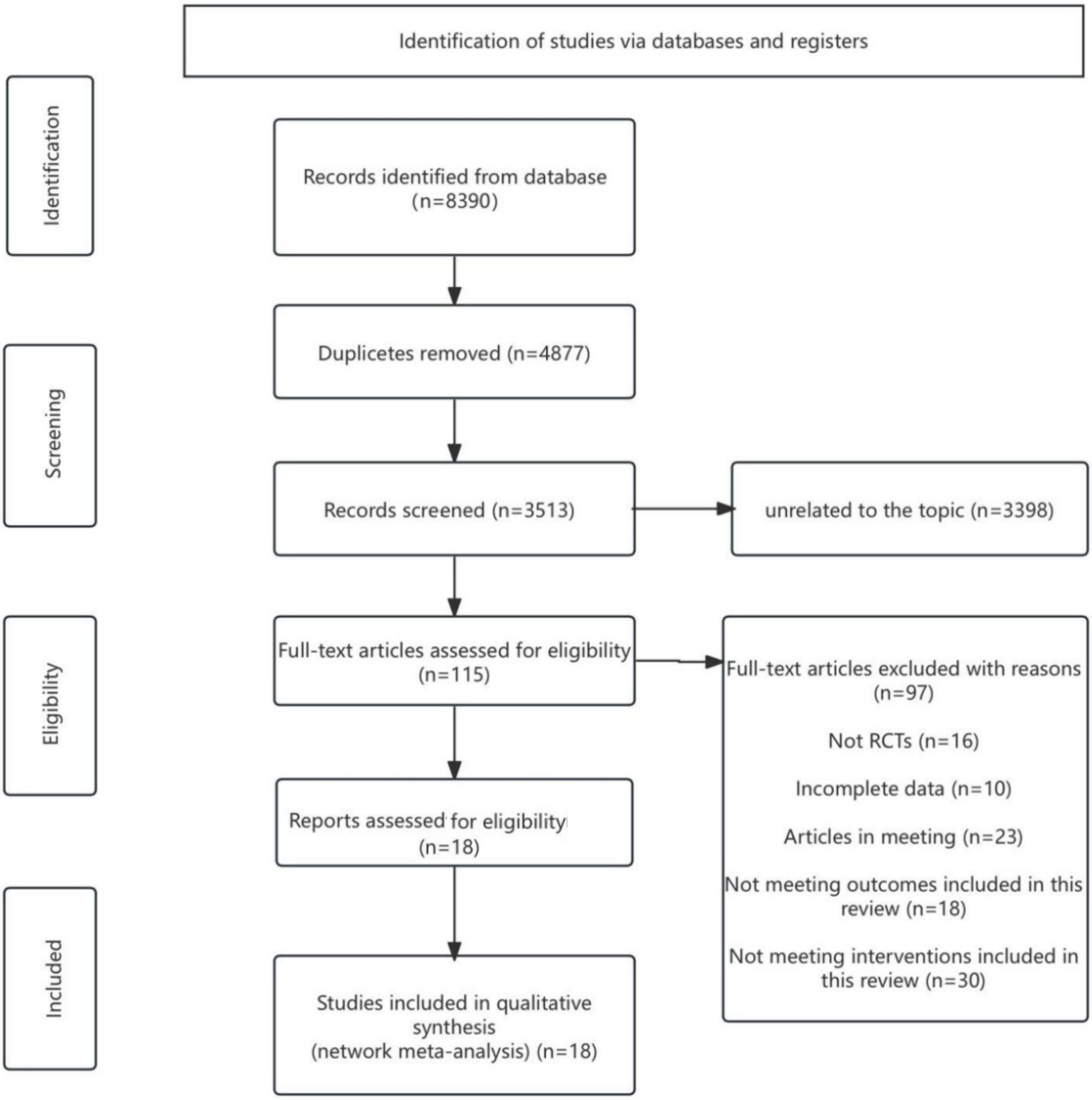

Fig. 1. Study selection flowchart. RCTs, randomized controlled trials.

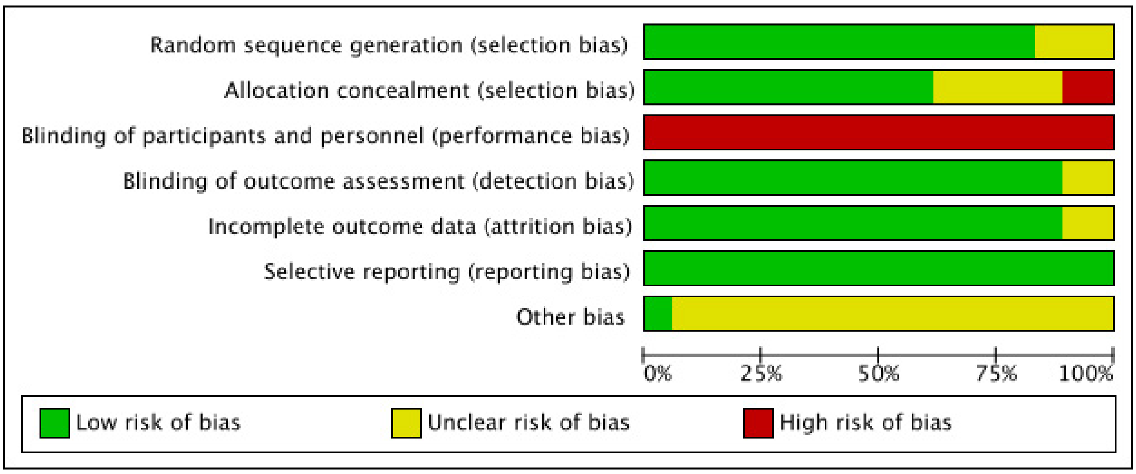

Fig. 2. Risk of bias graph.

2.5 Statistical Analysis

Data analysis was performed using R software. The package was employed to examine the correlation between different exercise intervention doses and the improvement of PSD. To assess heterogeneity among the included studies, we conducted heterogeneity tests using the I^2 statistic and Q test. An I^2 value $\geq$50% with a corresponding *p*-value < 0.1 from the Q test was considered indicative of significant heterogeneity. According to the latest Cochrane guidelines [25], model specification should be determined a priori rather than being based solely on the I^2 value.

Given the variability in the form, frequency, duration, and cycle of each intervention, a random-effects model was selected to better account for between-study differences and reflect the inherent uncertainty of the included studies. Based on the analytical results, we compared the mean differences between intervention and control groups using the standardized mean difference (SMD). Dose-response relationships between varying exercise doses and improvements in PSD were visualized through fitted dose-response curves. To evaluate the relative ranking of intervention efficacy, we calculated the Surface Under the Cumulative Ranking Curve (SUCRA), represented by the trapezoidal area under the curve. Potential publication bias was examined using funnel plots, which illustrate the distribution of effect sizes and standard errors to identify potential asymmetry. Statistical significance was defined as $p < 0.05$.

2.6 Quality Assessment

Quality assessment was independently conducted by two research teams, following a rigorous approach that utilized the Cochrane Risk of Bias Tool [25] to evaluate the methodological quality of the randomized controlled trials. The evaluation covered seven domains: selection bias (random sequence generation), selection bias (allocation concealment), performance bias, detection bias, attrition bias (loss to follow-up), reporting bias, and other biases. Each domain was rated as low risk, high risk, or unclear risk of bias based on the available evidence.

3. Results

3.1 Study Selection

A total of 8390 articles were retrieved from five electronic databases: PubMed (3059), Embase (1101), Web of Science (963), Cochrane (1038), and Ovid (2229). After removing 4877 duplicate records, 3513 articles remained after the initial screening. Titles and abstracts were reviewed, leading to the exclusion of 3398 irrelevant studies, and 115 articles were selected for full-text evaluation. Ultimately, 18 studies met the inclusion criteria and were incorporated into the final analysis (Fig. 1). Most of the included studies employed aerobic exercise as their primary intervention. Examples include: VR rehabilitation training [26]; music-assisted exercise [27]; early functional training [28]; caregiver-mediated exercise programs [29]; comprehensive rehabilitation training [30]; early rehabilitation training [31]; and general rehabilitation therapy [32].

Several studies incorporated moderate-intensity continuous endurance training and resistance exercise, such as resistance training [33], resistance and balance training [34], progressive resistance training [35], lower limb resistance training [36], and music-assisted upper limb rehabilitation [13].

Other studies focused on flexibility-based interventions, Baduanjin [11], Tai Chi [37,38], and yoga [10,39]. Additionally, one study adopted high-intensity interval training (HIIT) as the primary intervention [40]. The detailed characteristics of these studies are summarized in Table 2 (Ref. [10,11,13,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40]).

3.2 Study Characteristics

Table 2 summarizes the key characteristics of the 18 included studies, which encompass a total of 1206 participants aged between 43.1 and 81.14 years. The proportion of male participants was relatively higher. Both the experimental and control groups each included 603 participants. The intervention duration across studies ranged from 4 to 24 weeks. To assess depressive symptoms, eight studies utilized the Hamilton Depression Rating Scale (HAMD), three employed the Hospital Anxiety and Depression Scale (HADS), three used the Geriatric Depression Scale (GDS), and one employed the Beck Depression Inventory (BDI). Only one study adopted the Patient Health Questionnaire-9 (PHQ-9), the Major Depression Inventory (MDI), and the Mental Component Summary (MCS) of the SF-36.

Geographically, the studies were conducted by researchers from China (8), the United Kingdom (2), the United States (1), France (1), Australia (2), Switzerland (1), Sweden (1), New Zealand (1), and India (1) (Table 2).

3.3 Risk of Bias

Due to incomplete methodological descriptions, the risk of bias across the included studies was largely classified as high or unclear. All 18 studies reported randomization. However, only 15 (83.33%) provided detailed information on random sequence generation, and 11 studies described appropriate allocation concealment. Given the inherent challenges associated with blinding in exercise intervention studies, none of the studies blinded participants. However, 16 studies employed blinded outcome assessment. Incomplete outcome data indicated a loss rate of 11.11%, and selective reporting was noted in 100% of cases. Fig. 2 and Fig. 3 (Ref. [10,11,13,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40]) present the in-depth evaluation results of the included studies.

Table 2. Characteristics of the included studies.

Author	Country	Year	Population	Age (mean ± SD)	Sample size (T/C; M/F)	Intervention	Control	Outcome
Rosaria De Luca [26]	Switzerland	2024	Patients with post-stroke sequelae (Feb 2022–Mar 2023)	T: 53.50 ± 8.87; C: 43.10 ± 17.93	T: 10 (4/6); C: 10 (6/4)	Virtual Rehabilitation (VR) training; Duration: 8 weeks; Frequency: 3 times/week; Session: 60 min	CON	HAMD
Yihan Liu [11]	China	2024	Patients with post-stroke sequelae (Jun 2021–Feb 2023)	T: 58.86 ± 10.83; C: 56.22 ± 11.54	T: 50 (31/19); C: 50 (29/21)	Baduanjin training; Duration: 8 weeks; Frequency: 5 times/week; Session: 30 min	CON	HAMD
Taisheng Feng [33]	China	2024	Patients with post-stroke sequelae from (Aug 2023–Jul 2024)	T: 57.03 ± 13.40; C: 56.54 ± 10.23	T: 38 (27/11); C: 39 (31/8)	Unilateral resistance training; Duration: 4 weeks; Frequency: 5 times/week; Session: 60 min	CON	HAMD
Rita Lenoir dit Caron [10]	France	2024	Patients with post-stroke sequelae (Mar 2021–Sep 2022)	T: 67.1 ± 12.3; C: 68.2 ± 10.1	T: 18 (7/11); C: 18 (9/9)	Yoga training; Duration: 12 weeks; Frequency: 3 times/week; Session: 60 min	CON	BDI
Li Zhao [27]	China	2022	Patients with post-stroke sequelae (Dec 2019–Mar 2020)	T: 81.14 ± 8.33; C: 81.14 ± 8.33	T: 32 (NA); C: 33 (NA)	Musicokinetic training; Duration: 8 weeks; Frequency: twice a day; Session: 30 min	CON	HAMD
Jie Zhao [37]	China	2022	Patients with post-stroke sequelae (Apr–Aug 2020	T: 62.61 ± 12.88; C: 63.35 ± 12.90	T: 80 (42/38); C: 80 (39/41)	Sitting Tai Chi training; Duration: 12 weeks; Frequency: 3 times/week; Session: 40 min	CON	GDS-SF
Anna Palumbo [13]	United States	2022	Patients with post-stroke sequelae	T: 61.23 ± 9.13; C: 61.75 ± 12.75	T: 13 (5/8); C: 12 (8/4)	Music upper limb therapy integrated (MULT-I) training: Duration: 6 weeks; Frequency: 2 times/week; Session: 45 min	CON	PHQ-9
Purusotham Chippala [28]	India	2020	Patients with post-stroke sequelae (Dec 2013–Dec 2015)	T: 59.08 ± 10.83; C: 63.02 ± 9.14	T: 48 (31/17); C: 47 (31/16)	Early mobilization training; Frequency: 7 times/week; Session: 45 min	CON	HAMD
Rikke Steen Krawcyk [40]	United Kingdom	2019	Patients with post-stroke sequelae (Jan 2016–Jan 2018)	T: 63.7 ± 8.9; C: 63.7 ± 9.2	T: 31 (23/8); C: 32 (26/6)	High-intensity interval training (HIIT); Duration: 12 weeks; Frequency: 5 times/week; Session: 11 min	CON	MDI
Judith D. M. Vloothuis [29]	United Kingdom	2019	Patients with post-stroke sequelae (Apr 2014–Jul 2016)	T: 60.53 ± 14.82; C: 59.26 ± 15.01	T: 32 (21/11); C: 34 (20/14)	Caregiver-mediated training; Duration: 8 weeks; Frequency:5 times/week; Session: 30 min	CON	HADS
Chunmei Cheng [30]	China	2018	Patients with post-stroke sequelae (Jul 2014–Jun 2016)	T: 63.36 ± 9.08; C: 63.11 ± 11.95	T: 84 (39/45); C: 84 (44/40)	Comprehensive rehabilitation training; Duration: 24 weeks; Frequency: patient/family education once every bi-monthly, cognitive and rehabilitation training once every 2 months; Session: 60 min	CON	HADS
Bin Zhao [38]	China	2017	Patients with post-stroke sequelae (Jan–Dec 2015)	T: 53.85 ± 11.69; C: 51.38 ± 14.83	T: 30 (19/11); C: 30 (20/10)	Taijiquan training; Duration: 8 weeks; Frequency: 5 times/week; Session: 30 min	CON	HAMD

Table 2. Continued.

Author	Country	Year	Population	Age (mean ± SD)	Sample size (T/C; M/F)	Intervention	Control	Outcome
Birgit Vahlberg [34]	Sweden	2017	Patients with post-stroke sequelae (Oct 2009–Jul 2012)	T: 72.6 ± 5.5; C:73.7 ± 5.3	T: 34 (27/7); C: 33 (24/9)	Progressive resistance and balance (PRB) training; Duration: 12 weeks; Frequency: 2 times/week; Session: 75 minutes	CON	GDS-20
Li Ming [36]	China	2016	Patients with post-stroke sequelae (Aug 2014–May 2015)	T: 56.8 ± 10.8; C: 57.7 ± 12.3	T: 15 (10/5); C: 15 (9/6)	Intensive lower extremity function training; Duration: 4 weeks; Frequency:5 times/week; Session: 50 min	CON	HAMD
James Faulkner [31]	New Zealand	2015	Patients with post-stroke sequelae	T: 65 ± 11; C: 68 ± 10	T: 27 (15/12); C: 28 (14/14)	Early exercise training; Duration: 8 weeks; Frequency:2 times/week; Session: 90 min	CON	HADS
Weili Chan [39]	Australia	2012	Patients with post-stroke sequelae	T: 67.1 ± 15.4; C: 71.7 ± 12.7	T: 8 (7/1); C: 6 (5/1)	Yoga-and-exercise training; Duration: 6 weeks; Frequency: once/week; Session: 40 min	CON	GDS-15
J. Sims [35]	Australia	2009	Patients with post-stroke sequelae	T: 67.95 ± 14.76; C: 66.27 ± 16.01	T: 23 (14/9); C: 22 (13/9)	Progressive resistance training; Duration: 10 weeks; Frequency: 2 times/week; Session: 60 min	CON	MCS
Shuzhi Feng [32]	China	2003	Patients with post-stroke sequelae	T: 67.21 ± 10.12; C: 66.38 ± 9.07	T: 30 (18/12); C: 30 (16/14)	Rehabilitation training; Duration: 24 weeks; Frequency: once/week; Session: 60 min	CON	HAMD

HAMD, Hamilton Depression Rating Scale; CON, control; GDS-SF, Geriatric Depression Scale-Short Form; GDS-20, Geriatric Depression Scale-20; GDS-15, Geriatric Depression Scale-15; NA, not available; PHQ-9, Patient Health Questionnaire-9; SD, standard deviation; BDI, Beck Depression Inventory; HADS, Hospital Anxiety and Depression Scale; MCS, Mental Component Summary; MDI, Major Depression Inventory; T, treatment group; C, control group; M, male; F, female.

Table 3. Cumulative ranking probabilities of different exercise intervention models.

Intervention	1	2	3	4	5	6	7	8
MAE	0.004725	0.018665	0.03875	0.06362	0.102025	0.17087	0.32765	1
CE	0.005695	0.06095	0.254395	0.583135	0.8683	0.983525	0.99929	1
CG	0.000815	0.00712	0.031285	0.09786	0.26021	0.58755	0.927095	1
RT	0.594775	0.75394	0.829925	0.87729	0.91468	0.94977	0.9839	1
HIIT	0.136635	0.29645	0.406005	0.4882	0.57396	0.687095	0.859025	1
MICT	0.039025	0.161355	0.316815	0.47402	0.6421	0.808305	0.95352	1
TOMA	0.09865	0.36288	0.620705	0.792745	0.90436	0.96808	0.99407	1
YOGA	0.11968	0.33864	0.50212	0.62313	0.734365	0.844805	0.95545	1

CG, control group; CE, combined exercise; RT, resistance training; MAE, mixed aerobic exercise; HIIT, high-intensity interval training; MICT, moderate-intensity continuous training; TOMA, traditional martial arts; YOGA, yoga.

3.4 Meta-Analysis

3.4.1 Forest Plot Results

First, the subgroup analysis based on exercise intervention frequency showed that when the intervention frequency was less than 5 times per week, the standardized mean difference (SMD) was –0.14 (95% confidence interval [CI]: –0.44, 0.16) ($p = 0.35$). In contrast, when the intervention frequency was at least 5 times per week, the SMD was –0.42 (95% CI: –0.61, –0.22) ($p < 0.01$), indicating that high-frequency exercise ($\geq$5 times/week) significantly improved PSD (Fig. 4, Ref. [10,11,13,26,27,28,29,31,32,33,34,35,36,37,38,39,40]).

The subgroup analysis based on intervention duration revealed that for interventions lasting less than eight weeks, the standardized mean difference (SMD) was –0.47 (95% CI: –0.66 to –0.28) ($p < 0.01$), indicating that short-term interventions ($\leq$8 weeks) significantly improved PSD. For interventions not exceeding 12 weeks, the SMD was 0.13 (95% CI: –0.07, 0.33) ($p = 0.21$), while for those exceeding 12 weeks, the SMD was –0.38 (95% CI: –1.36, 0.59) ($p = 0.44$). The analysis demonstrated a statistically significant difference among the three duration groups ($p = 0.0001$), indicating that exercise durations had a significant impact on PSD outcomes (Fig. 5, Ref. [10,11,13,26,27,29,30,31,32,33,34,35,36,37,38,39,40]).

Additionally, subgroup analysis based on single-session exercise duration revealed that for interventions lasting up to 30 minutes, the standardized mean difference (SMD) was –0.59 (95% CI: –0.83 to –0.34) ($p < 0.01$), suggesting that short-duration ($\leq$30 min) exercise sessions significantly improved PSD. For interventions lasting up to 60 minutes, the SMD was –0.11 (95% CI: –0.32, 0.10) ($p = 0.31$), and for those exceeding 60 minutes, the SMD was 0.05 (95% CI: –0.31, 0.40) ($p = 0.80$). The analysis revealed a statistically significant difference among the three exercise duration groups ($p = 0.003$) (Fig. 6, Ref. [10,11,13,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40]), demonstrating that PSD outcomes were significantly influenced by exercise duration (Fig. 6).

3.4.2 Cumulative Ranking Results

Eight exercise intervention measures were compared, and cumulative probability graphs of the eight exercise interventions (Fig. 7) were generated based on the data in Table 3, with the SUCRA values subsequently calculated. SUCRA provides an aggregated score representing the cumulative probability ranking. The eight exercise interventions were ranked from the most to least effective according to their SUCRA value, where a higher SUCRA value indicates greater intervention efficacy. The SUCRA values of each exercise intervention are presented in tabular form. It was observed that the SUCRA value for RT was the highest (87.2%), indicating that RT was the most effective intervention, followed by TOMA (74.2%). Thus, the hierarchy of exercise interventions may be as follows: RT, TOMA, YOGA, CE, HIIT, MICT, CG, and MAE.

We used the ‘GGPLOT’ package in R (49) to plot exercise dose-response relationships and assess significant nonlinear responses for each post-stroke depression symptom across the eight exercise models (Fig. 8). The vertical axis represents the improvement effect, while the horizontal axis represents the exercise dose. A negative dose-response relationship was observed, where the depression-improving effects of MAE, CE, CG, RT, HIIT, MICT, TOMA, and YOGA decreased as the dose of exercise increased. Among these, RT showed the steepest downward trend. None of the exercise intervention curves showed a clear ‘plateau’ or ‘reversal’ trend, indicating that the optimal exercise dose range has not yet been determined within the scope of this study. Therefore, future studies should expand the sample size and vary the dose parameters of each intervention model. Increasing stimulation intensity, extending the intervention duration, frequency, and overall period may help identify the optimal intervention dose for each exercise model. Additionally, the confidence intervals of all eight exercise models crossed zero and were statistically non-significant (Fig. 8).

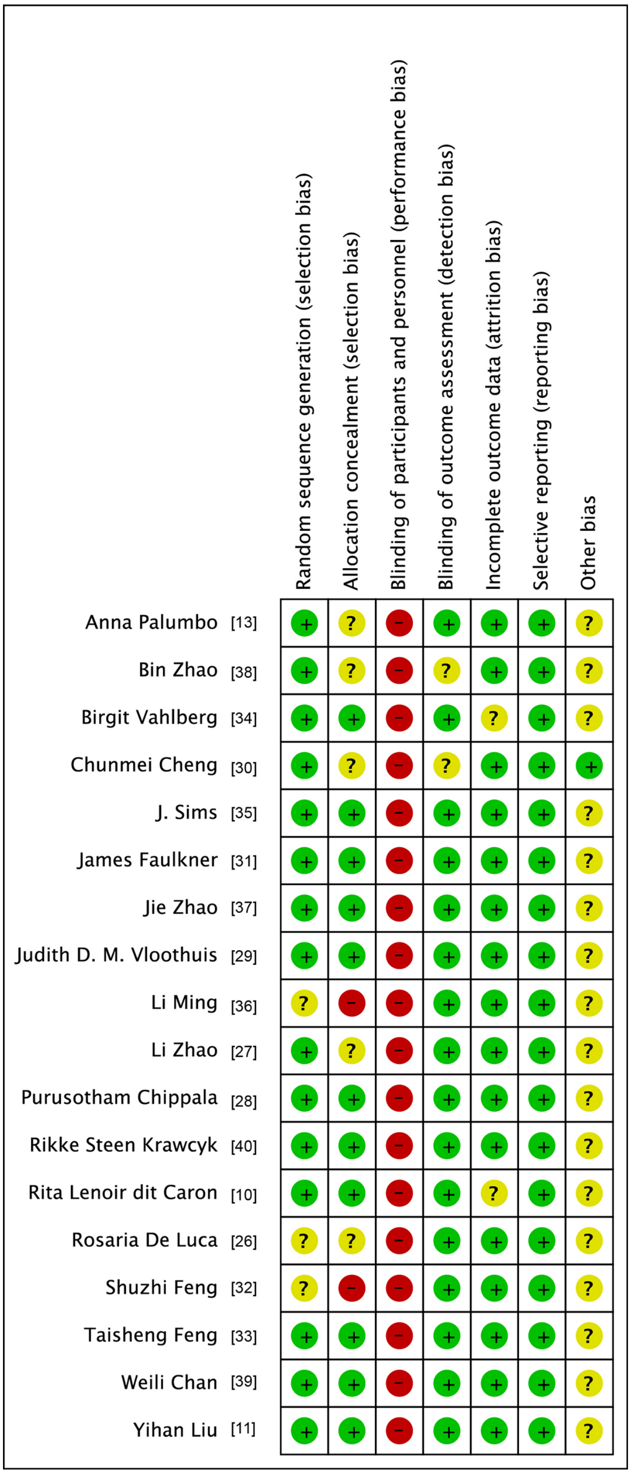

Fig. 3. Risk of bias summary.

3.4.3 Publication Bias Results

Publication bias was assessed using a funnel plot. The distribution of studies on both sides of the funnel appeared nearly symmetrical, suggesting no significant publication bias. Sensitivity analysis further revealed that no single study had a significant influence on the overall results, indicating that our findings are robust and stable (Fig. 9A–C).

4. Discussion

After conducting a comprehensive database search and iterative screening of relevant literature, we successfully included 18 studies in this meta-analysis. These studies encompassed data from 1206 stroke patients with PSD across nine different countries, all of whom received exercise interventions followed by emotional assessments. The results indicate that exercise interventions significantly alleviate depressive symptoms in stroke patients, which is consistent with previous research findings [31].

Exercise therapy has been shown to increase the concentrations of serotonin (5-hydroxytryptamine [5-HT]) and norepinephrine (NE) in the brain, as well as enhance dopamine release by activating the phosphatidylinositol C signaling pathway [41,42]. Exercise also modulates the expression of brain-derived neurotrophic factor (BDNF), thereby promoting hippocampal neurogenesis, which contributes to the reduction of depressive symptoms [43,44]. Furthermore, exercise interventions have been found to reduce several immune-inflammatory markers, such as interleukin-1, interleukin-6, and tumor necrosis factor-α, thus reducing neuroinflammation and contributing to the alleviation of depressive symptoms [45]. Previous studies have also confirmed that exercise can improve hypothalamic-pituitary-adrenal (HPA) axis function, increase dopamine levels in the prefrontal cortex, and regulate the expression of glucocorticoid receptors [46]. In addition, exercise enhances patients' sense of self-efficacy and psychological resilience, which helps reduce symptoms of anxiety and fatigue [12].

By reviewing relevant literature, it has been demonstrated that exercise benefits both physical and mental health [14]. Previous systematic reviews have shown that moderate- to high-intensity exercise prescriptions have a positive influence on the improvement of PSD [47], whereas the effects of low-intensity exercise on post-stroke depression remain unclear. The maximum benefit appears to occur with at least 150 minutes per week of aerobic exercise, resistance training, or combined aerobic interventions. Although the "dose-effect" relationship between exercise dosage and the efficacy of depression treatment remains inconsistent, previous clinical research has indicated a dose-response effect of exercise interventions for depression [48]. Our findings further support this view. As shown in Fig. 4, the standardized mean difference (SMD) of –0.42 indicates the level of improvement in the high-frequency group compared with the low-frequency group on a specific mental health measure. However, the standardized mean difference alone cannot serve as the sole criterion for judgment. Its interpretation must be integrated with additional background information. Although the high-frequency group demonstrated a statistically significant effect ($p < 0.01$), the subgroup p-value of 0.13 suggests no significant difference between the frequency subgroups. These findings imply that the effects of the two frequency

Study or Subgroup	Experimetal Mean	SD	Total	Control Mean	SD	Total	Weight	Standard Mean Difference IV, Random, 95 CI
1.1.1 Less than 5 times per week								
Anna Palumbo [13]	3.15	3	13	3.44	5.7	12	4.0%	−0.06 [−0.85, 0.72]
Birgit Vahlberg [34]	−1	5	34	−1.5	4	33	6.7%	0.11 [−0.37, 0.59]
J. Sims [35]	14.19	23.26	23	7.82	1.6	22	5.5%	0.38 [−0.21, 0.97]
James Faulkner [31]	3.5	3.7	27	3.6	3.2	28	6.1%	−0.03 [−0.56, 0.50]
Jie Zhao [37]	5.85	1.56	80	5.53	1.95	80	8.6%	0.18 [−0.13, 0.49]
Li Zhao [27]	16.38	9.92	32	29.7	19.43	33	6.3%	−0.85 [−1.36, −0.34]
Rita Lenoir dit Caron [10]	13	10.22	18	11.5	11.26	18	5.0%	0.14 [−0.52, 0.79]
Rosaria De Luca [26]	11.5	2.78	10	12	5.19	10	3.5%	−0.12 [−0.99, 0.76]
Shuzhi Feng [32]	8.7	5.1	30	14.9	8.1	30	6.1%	−0.90 [−1.44, −0.37]
Weili Chan [39]	2	3.33	8	3	0.74	6	2.6%	−0.36 [−1.43, 0.71]
Subtotal (95% CI)			275			272	54.4%	-0.14[-0.44,-0.16]
Heterogeneity: Tau² = 0.14; Chi² = 24.23, df = 9 (P = 0.004); I² = 63%								
Test for overall effect: Z = 0.94 (P = 0.35)								
1.1.2 At least 5 times per week								
Bin Zhao [38]	6.27	3.19	30	8.77	3.07	30	6.2%	−0.79 [−1.31, −0.26]
Judith D. M. Vloothuis [29]	2.88	2.54	34	4.28	2.99	32	6.5%	−0.50 [−0.99, −0.01]
Li Ming [36]	12.13	5.44	15	15.07	4.76	15	4.4%	−0.56 [−1.29, 0.17]
Purusotham Chippala [28]	5.9	4.3	48	6.7	4.6	47	7.5%	−0.18 [−0.58, 0.22]
Rikke Steen Krawcyk [40]	6	7.41	31	7	8.15	32	6.5%	−0.13 [−0.62, 0.37]
Taisheng Feng [33]	3	3.89	38	4	4.44	39	7.0%	−0.24 [−0.69, 0.21]
Yihan Liu [11]	8.54	3.44	50	11.48	5.06	50	7.5%	−0.67 [−1.08, −0.27]
Subtotal (95% CI)			246			245	45.6%	-0.42[-0.61,-0.22]
Heterogeneity: Tau² = 0.01; Chi² = 7.02, df = 6 (P = 0.32); I² = 15%								
Test for overall effect: Z = 4.19 (P < 0.0001)								
Total (95% CI)			521			517	100.0%	-0.27[-0.47,-0.07]
Heterogeneity: Tau² = 0.09; Chi² = 37.63, df = 16 (P = 0.002); I² = 57%								
Test for overall effect: Z = 2.68 (P = 0.007)								
Test for subgroup differences: Chi² = 2.29, df = 1 (P = 0.13), I² = 56.3%								

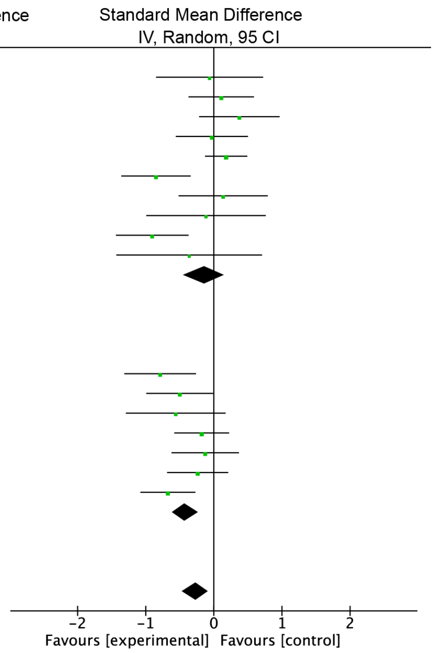

Fig. 4. Forest plot on exercise frequency. Key statistical value: Standardized mean difference (SMD)—The SMD quantifies the differences between two group means, standardized by the variability of the data. It is typically employed for continuous outcomes to enable comparison across studies. CI, confidence interval; Std., standardized; IV, inverse variance.

Study or Subgroup	Experimetal Mean	SD	Total	Control Mean	SD	Total	Weight	Standard Mean Difference IV, Random, 95 CI
1.1.1 No more than 8 weeks								
Anna Palumbo [13]	3.15	3	13	3.44	5.7	12	4.0%	−0.06 [−0.85, 0.72]
Bin Zhao [38]	6.27	3.19	30	8.77	3.07	30	6.1%	−0.79 [−1.31, −0.26]
James Faulkner [31]	3.5	3.7	27	3.6	3.2	28	6.1%	−0.03 [−0.56, 0.50]
Judith D. M. Vloothuis [29]	2.88	2.54	34	4.28	2.99	32	6.4%	−0.50 [−0.99, −0.01]
Li Ming [36]	12.13	5.44	15	15.07	4.76	15	4.4%	−0.56 [−1.29, 0.17]
Li Zhao [27]	16.38	9.92	32	29.7	19.43	33	6.3%	−0.85 [−1.36, −0.34]
Rosaria De Luca [26]	11.5	2.78	10	12	5.19	10	3.5%	−0.12 [−0.99, 0.76]
Taisheng Feng [33]	3	3.89	38	4	4.44	39	6.9%	−0.24 [−0.69, 0.21]
Weili Chan [39]	2	3.33	8	3	0.74	6	2.7%	−0.36 [−1.43, 0.71]
Yihan Liu [11]	8.54	3.44	50	11.48	5.06	50	7.4%	−0.67 [−1.08, −0.27]
Subtotal (95% CI)			257			255	53.7%	-0.47 [-0.66,-0.28]
Heterogeneity: Tau² = 0.01; Chi² = 10.01, df = 9 (P = 0.35); I² = 10%								
Test for overall effect: Z = 4.89 (P < 0.00001)								
1.1.2 8-12 weeks								
Birgit Vahlberg [34]	−1	5	34	−1.5	4	33	6.6%	0.11 [−0.37, 0.59]
J. Sims [35]	14.19	23.26	23	7.82	11.6	22	5.5%	0.34 [−0.25, 0.93]
Jie Zhao [37]	5.85	1.56	80	5.53	1.95	80	8.4%	0.18 [−0.13, 0.49]
Rikke Steen Krawcyk [40]	6	7.41	31	7	8.15	32	6.4%	−0.13 [−0.62, 0.37]
Rita Lenoir dit Caron [10]	13	10.22	18	11.5	11.26	18	5.0%	0.14 [−0.52, 0.79]
Subtotal (95% CI)			186			185	31.8%	0.13 [-0.07,-0.33]
Heterogeneity: Tau² = 0.00; Chi² = 1.62, df = 4 (P = 0.80); I² = 0%								
Test for overall effect: Z = 1.25 (P = 0.21)								
1.1.3 more than 12 weeks								
Chunmei Cheng [30]	6.8	4.6	84	6.4	4.2	84	8.4%	0.09 [−0.21, 0.39]
Shuzhi Feng [32]	8.7	5.1	30	14.9	8.1	30	6.0%	−0.90 [−1.44, −0.37]
Subtotal (95% CI)			114			114	14.5%	-0.38 [-1.36,0.59]
Heterogeneity: Tau² = 0.45; Chi² = 10.11, df = 1 (P = 0.001); I² = 90%								
Test for overall effect: Z = 0.77 (P = 0.44)								
Total (95% CI)			557			554	100.0%	-0.25 [-0.45,-0.05]
Heterogeneity: Tau² = 0.10; Chi² = 41.29, df = 16 (P = 0.0005); I² = 61%								
Test for overall effect: Z = 2.42 (P = 0.02)								
Test for subgroup differences: Chi² = 18.12, df = 2 (P = 0.0001), I² = 89.0%								

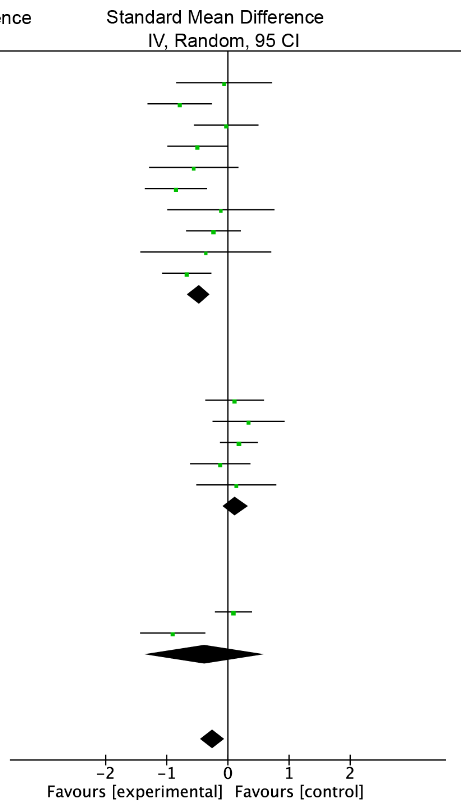

Fig. 5. Forest plot of exercise cycle.

groups overlap rather than exhibiting a linear improvement trend.

However, existing clinical studies have reported that low-dose exercise interventions (at least 3–5 sessions per

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Standard Mean Difference IV, Random, 95 CI
1.1.1 Within 30 minutes								
Bin Zhao [38]	6.27	3.19	30	8.77	3.07	30	5.7%	−0.79 [−1.31, −0.26]
Judith D. M. Vloothuis [29]	2.88	2.54	34	4.28	2.99	32	6.0%	−0.50 [−0.99, −0.01]
Li Zhao [27]	16.38	9.92	32	29.7	19.43	33	5.8%	−0.85 [−1.36, −0.34]
Rikke Steen Krawcyk [40]	6	7.41	31	7	8.15	32	6.0%	−0.13 [−0.62, 0.37]
Yihan Liu [11]	8.54	3.44	50	11.48	5.06	50	6.9%	−0.67 [−1.08, −0.27]
Subtotal (95% CI)			177			177	30.4%	-0.59 [-0.83,-0.34]
Heterogeneity: Tau² = 0.02; Chi² = 5.21, df = 4 (P = 0.27); I² = 23%								
Test for overall effect: Z = 4.69 (P < 0.00001)								
1.1.2 30-60 minutes								
Anna Palumbo [13]	3.15	3	13	3.44	5.7	12	3.7%	−0.06 [−0.85, 0.72]
Chunmei Cheng [30]	6.8	4.6	84	6.4	4.2	84	8.1%	0.09 [−0.21, 0.39]
J. Sims [35]	14.19	23.26	23	7.82	11.6	22	5.1%	0.34 [−0.25, 0.93]
Jie Zhao [37]	5.85	1.56	80	5.53	1.95	80	8.0%	0.18 [−0.13, 0.49]
Li Ming [36]	12.13	5.44	15	15.07	4.76	15	4.0%	−0.56 [−1.29, 0.17]
Purusotham Chippala [28]	5.9	4.3	48	6.7	4.6	47	6.9%	−0.18 [−0.58, 0.22]
Rita Lenoir dit Caron [10]	13	10.22	18	11.5	11.26	18	4.6%	0.14 [−0.52, 0.79]
Rosaria De Luca [26]	11.5	2.78	10	12	5.19	10	3.2%	−0.12 [−0.99, 0.76]
Shuzhi Feng [32]	8.7	5.1	30	14.9	8.1	30	5.6%	−0.90 [−1.44, −0.37]
Taisheng Feng [33]	3	3.89	38	4	4.44	39	6.4%	−0.24 [−0.69, 0.21]
Weili Chan [39]	2	3.33	8	3	0.74	6	2.4%	−0.36 [−1.43, 0.71]
Subtotal (95% CI)			367			363	57.8%	-0.11 [-0.32,-0.10]
Heterogeneity: Tau² = 0.05; Chi² = 18.03, df = 10 (P = 0.05); I² = 45%								
Test for overall effect: Z = 1.01 (P = 0.31)								
1.1.3 More than 60 minutes								
Birgit Vahlberg [34]	−1	5	34	−1.5	4	33	6.1%	0.11 [−0.37, 0.59]
James Faulkner [31]	3.5	3.7	27	3.6	3.2	28	5.6%	−0.03 [−0.56, 0.50]
Subtotal (95% CI)			61			61	11.8%	-0.05 [-0.31,-0.40]
Heterogeneity: Tau² = 0.00; Chi² = 0.14, df = 1 (P = 0.71); I² = 0%								
Test for overall effect: Z = 0.26 (P = 0.80)								
Total (95% CI)			605			601	100.0%	-0.24 [-0.43,-0.06]
Heterogeneity: Tau² = 0.09; Chi² = 41.30, df = 17 (P = 0.0008); I² = 59%								
Test for overall effect: Z = 2.54 (P = 0.01)								
Test for subgroup differences: Chi² = 11.58, df = 2 (P = 0.003), I² = 82.7%								

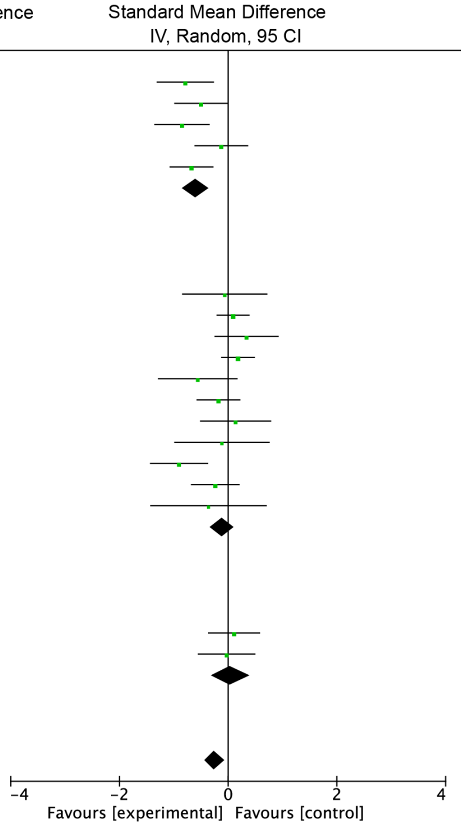

Fig. 6. Forest plot of exercise duration.

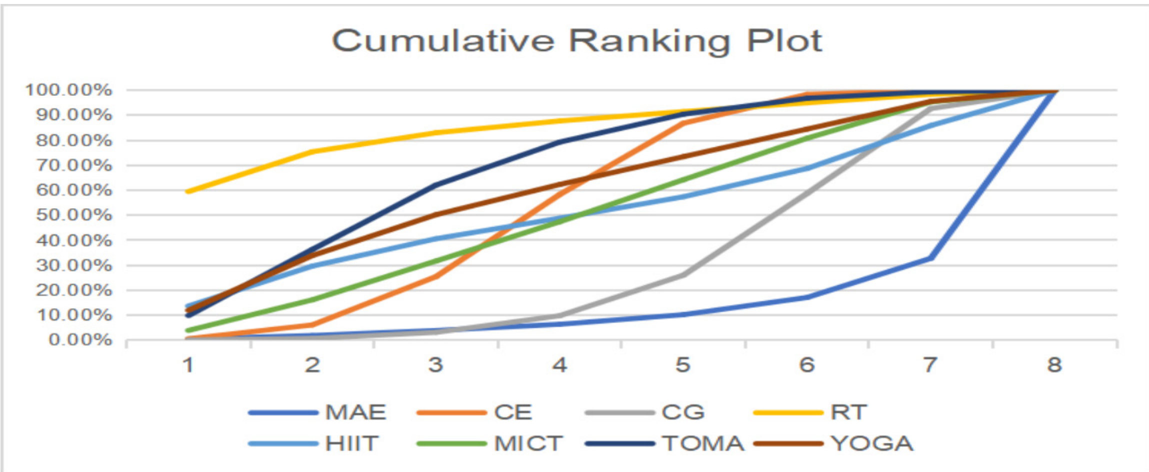

Fig. 7. Cumulative ranking plot. CG, control group; CE, combined exercise; RT, resistance training; MAE, mixed aerobic exercise; HIIT, high-intensity interval training; MICT, moderate-intensity continuous training; TOMA, traditional martial arts; YOGA, yoga.

week, lasting 45–60 min per session, and continuing for more than 12 weeks) effectively alleviate depressive symptoms [49]. Moreover, a meta-analysis revealed that walking, yoga, and resistance training exercises can reduce the risk of depression and depressive symptoms in healthy individuals, with greater exercise duration and intensity yielding additional benefits [50].

It has been reported that prolonging exercise duration can effectively enhance cardiovascular adaptability, improve physical recovery and fat oxidation, and exert a positive effect on alleviating depression [51]. Furthermore, long-term exercise enhances muscular and joint adaptability, improves exercise efficiency, reduces the risk of exercise-related injuries, ensures greater adherence to training programs, and promotes the recovery of the patients' mental health [12].

Participants included in this study exhibited varying individual characteristics, including differences in exercise

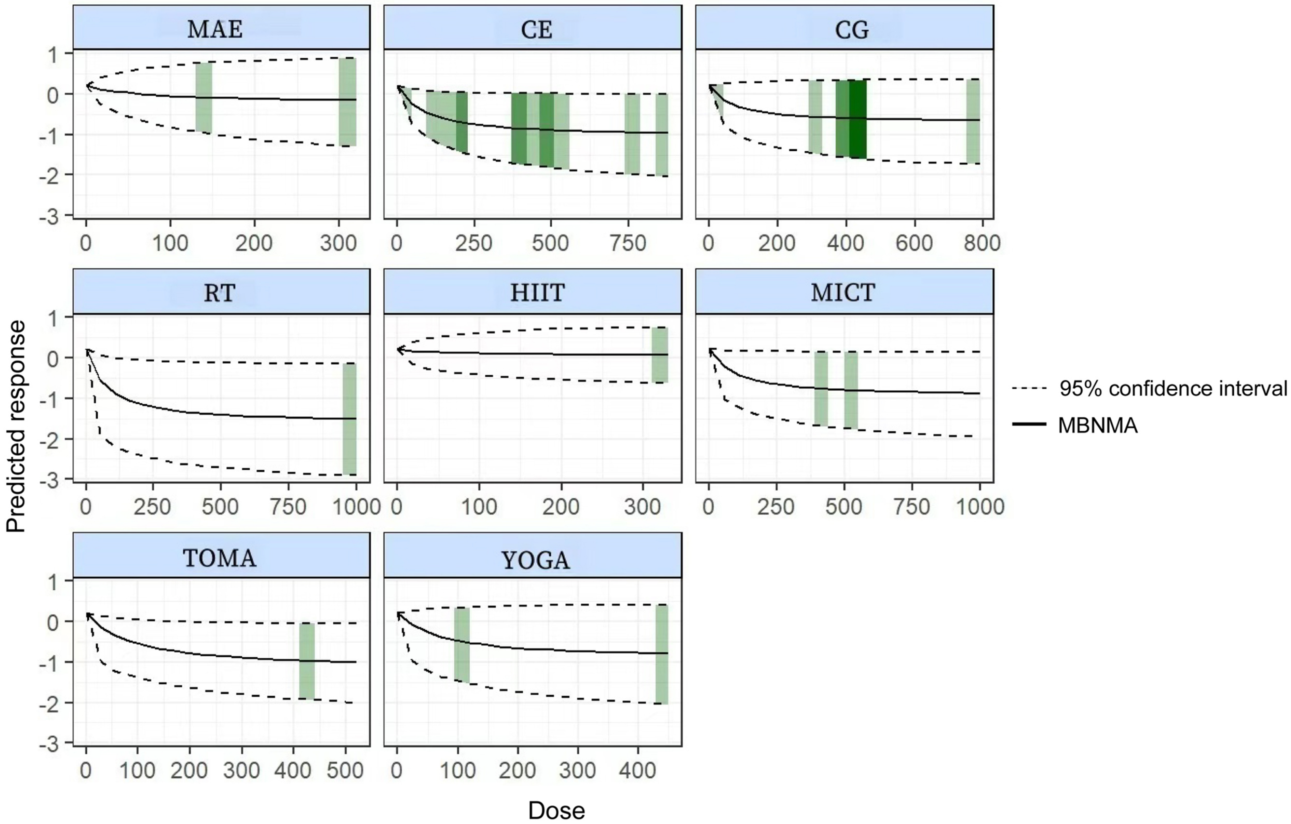

Fig. 8. Network comparison of exercise intervention models. The figure shows the differential analysis of various exercise interventions, including MAE, CE, CG, RT, HIIT, MICT, TOMA, and YOGA. MBNMA, Multi-treatment Bayesian Network Meta-Analysis.

adaptability, physical condition, and psychological state. We roughly determined the influence of different exercise forms, frequencies, and durations on the degree of PSD. To better compare the effects of various exercise doses, we calculate the metabolic equivalent of task (MET) values of each intervention included in the study.

Limitations of the Review

This review has several notable limitations. Due to regional, age-related, economic, and cultural differences in inclusion criteria and the inherent limitations of data analysis methods, the number of high-quality randomized controlled trials meeting the inclusion criteria was limited in assessing the effects of exercise interventions on PSD in our meta-analysis. Furthermore, determining the optimal combination of exercise parameters requires comprehensive consideration of exercise intensity and duration. The total exercise duration for the low-frequency group was generally longer than that for the high-frequency group, while the intervention intensity differed across studies included in both categories.

Moreover, the types and content of exercise interventions varied among the included studies, introducing potential bias in estimating the efficacy of the interventions. Additionally, sample size variation may have influenced the statistical outcomes. For instance, the study included a relatively small sample size [39]. Although Fig. 6 shows that the short-term exercise appeared more effective, potential confounding factors related to exercise intensity cannot be excluded. Thus, it remains uncertain whether the observed effects are due to the exercise duration itself or the differences in intensity. Due to the current lack of clinical evidence on the independent effects of exercise frequency, duration, and cycle on PSD, future research should include high-quality clinical studies to explore the optimal exercise dosage in greater depth [48].

Finally, given the variability across all existing studies, these factors should be carefully considered when designing future research to determine the optimal exercise prescription for patients with PSD. Such studies should employ multi-center collaboration to expand sample sizes and utilize multi-dimensional approaches to evaluate different exercise intervention models and dosages. Establishing a long-term follow-up database will be crucial for identifying the most suitable exercise modalities and optimal dosages, as well as for evaluating the long-term effects of various exercise interventions on depressive symptoms.

IMR Press

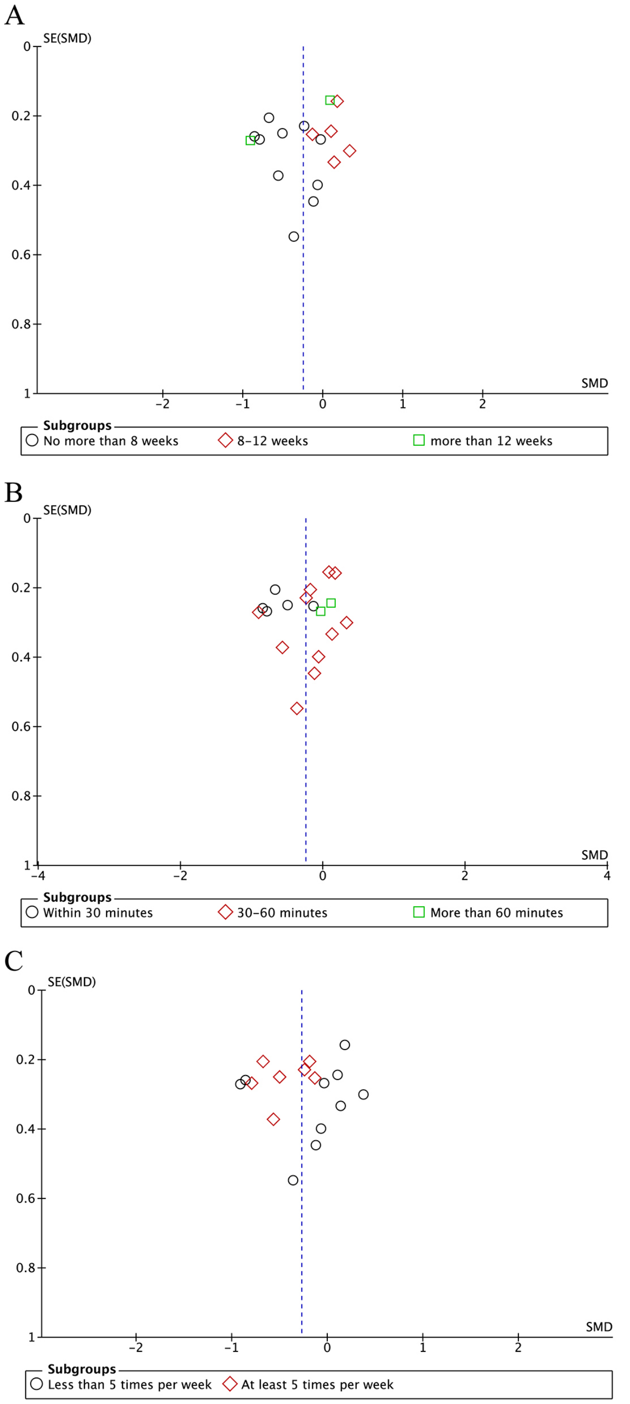

Fig. 9. Funnel plot for publication bias. (A) The degree of cycle bias. (B) The degree of duration bias. (C) The degree of frequency bias. SE, standard error; SMD, standardized mean difference.

5. Conclusion

Notably, the findings of this study suggest that all exercise intervention models exert beneficial effects on PSD. Among these, resistance training demonstrates the greatest potential to significantly alleviate PSD. However, the most effective dose of resistance exercises has not been established. These provide valuable reference data for developing personalized exercise prescriptions in clinical settings. Future research should include long-term follow-up and high-quality clinical studies to further validate the correlation between exercise dose and its therapeutic effect on PSD. Expanding sample sizes and enhancing data application systems related to stroke rehabilitation will contribute to a more comprehensive understanding of exercise-based recovery mechanisms. This, in turn, may offer new insights and approaches for advancing the integration of exercise therapy into brain-heart rehabilitation.

Key Points

• When the exercise duration is less than 8 weeks, performed 5 times per week, with each session lasting within 30 minutes, it yields the most significant therapeutic effect in improving post-stroke depression (PSD).

• Resistance training is the most effective among all exercise models and can more prominently alleviate depressive symptoms.

• Although resistance exercise shows outstanding results, its optimal intervention dose remains undetermined and requires further investigation.

• The study provides practical guidance for developing personalized exercise prescriptions in stroke rehabilitation, enabling clinicians to customize treatment plans based on individual patient conditions, thereby improving treatment efficacy and quality of life.

• Long-term follow-up and high-quality studies are needed to clarify the precise relationship between exercise intervention dose and therapeutic outcomes in PSD.

Availability of Data and Materials

The data analyzed in this study are available from the corresponding author upon reasonable request.

Author Contributions

Conceptualization, XLF and QCP; methodology, WD; software, XLF; validation, XYD, XQY and SH; formal analysis, XLF; investigation, XLF; resources, QCP; data curation, XYD; writing—original draft preparation, XLF; writing—review and editing, XLF; visualization, WD; supervision, SH; project administration, WD. All authors contributed to the important editorial changes in the manuscript. All authors have read and agreed to the published version of the manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

Not applicable.

Acknowledgment

We gratefully acknowledge the support provided by scientific research at The Third People's Hospital of Hubei

Province (Zhongshan Hospital), Traditional Chinese and Western Medicine Hospital of Wuhan, Tongji Medical College, Huazhong University of Science and Technology and Xianning Central Hospital.

Funding

This research received no external funding.

Conflicts of Interest

The authors declare no conflicts of interest.

Supplementary Material

Supplementary material associated with this article can be found, in the online version, at https://doi.org/10.31083/BJHM58254.

References

[1] Iadecola C, Buckwalter MS, Anrather J. Immune responses to stroke: mechanisms, modulation, and therapeutic potential. The Journal of Clinical Investigation. 2020; 130: 2777–2788. https://doi.org/10.1172/JCI135530

[2] Feske SK. Ischemic Stroke. The American Journal of Medicine. 2021; 134: 1457–1464. https://doi.org/10.1016/j.amjmed.2021.07.027

[3] Chun HYY, Ford A, Kutlubaev MA, Almeida OP, Mead GE. Depression, Anxiety, and Suicide After Stroke: A Narrative Review of the Best Available Evidence. Stroke. 2022; 53: 1402–1410. https://doi.org/10.1161/STROKEAHA.121.035499

[4] Medeiros GC, Roy D, Kontos N, Beach SR. Post-stroke depression: A 2020 updated review. General Hospital Psychiatry. 2020; 66: 70–80. https://doi.org/10.1016/j.genhosppsych.2020.06.011

[5] Villa RF, Ferrari F, Moretti A. Post-stroke depression: Mechanisms and pharmacological treatment. Pharmacology & Therapeutics. 2018; 184: 131–144. https://doi.org/10.1016/j.pharmthera.2017.11.005

[6] Bellón JÁ. Exercise for the treatment of depression. BMJ (Clinical Research Ed.). 2024; 384: q320. https://doi.org/10.1136/bmj.q320

[7] Xie Y, Wu Z, Sun L, Zhou L, Wang G, Xiao L, et al. The Effects and Mechanisms of Exercise on the Treatment of Depression. Frontiers in Psychiatry. 2021; 12: 705559. https://doi.org/10.3389/fpsyt.2021.705559

[8] Pang MYC, Charlesworth SA, Lau RWK, Chung RCK. Using aerobic exercise to improve health outcomes and quality of life in stroke: evidence-based exercise prescription recommendations. Cerebrovascular Diseases. 2013; 35: 7–22. https://doi.org/10.1159/000346075

[9] Church G, Ali A, Smith CL, Broom D, Sage K. Examining Clinical Practice Guidelines for Exercise and Physical Activity as Part of Rehabilitation for People with Stroke: A Systematic Review. International Journal of Environmental Research and Public Health. 2022; 19: 1707. https://doi.org/10.3390/ijerph19031707

[10] Lenoir Dit Caron R, Verdun S, Triquenot-Bagan A, Tourny C, Coquart J. Yoga in the Rehabilitation of Post-Stroke Sequelae: A Non-Inferiority Randomized Controlled Trial. Journal of Integrative and Complementary Medicine. 2024; 30: 543–553. https://doi.org/10.1089/jicm.2023.0315

[11] Liu Y, Chen C, Du H, Xue M, Zhu N. Impact of Baduanjin exercise combined with rational emotive behavior therapy on sleep and mood in patients with poststroke depression: A randomized controlled trial. Medicine. 2024; 103: e38180. https://doi.org/10.1097/MD.0000000000038180

[12] Li G, Tao X, Lei B, Hou X, Yang X, Wang L, et al. Effects of exercise on post-stroke cognitive function: a systematic review and meta-analysis of randomized controlled trials. Topics in Stroke Rehabilitation. 2024; 31: 645–666. https://doi.org/10.1080/10749357.2024.2356393

[13] Palumbo A, Aluru V, Battaglia J, Geller D, Turry A, Ross M, et al. Music Upper Limb Therapy-Integrated Provides a Feasible Enriched Environment and Reduces Post-stroke Depression: A Pilot Randomized Controlled Trial. American Journal of Physical Medicine & Rehabilitation. 2022; 101: 937–946. https://doi.org/10.1097/PHM.0000000000001938

[14] Song YY, Sun WJ, Wang C, Tian YM, Liu H, Jiang Y. Effects of multicomponent exercise on quality of life, depression and anxiety among stroke survivors: A systematic review and meta-analysis. Journal of Clinical Nursing. 2023; 32: 7677–7690. https://doi.org/10.1111/jocn.16853

[15] Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ (Clinical Research Ed.). 2021; 372: n71. https://doi.org/10.1136/bmj.n71

[16] Robinson KA, Akinyede O, Dutta T, Sawin VI, Li T, Spencer MR, et al. Framework for Determining Research Gaps During Systematic Review: Evaluation. Agency for Healthcare Research and Quality (US): Rockville (MD). 2013.

[17] Hamilton M. A rating scale for depression. Journal of Neurology, Neurosurgery, and Psychiatry. 1960; 23: 56–62. https://doi.org/10.1136/jnnp.23.1.56

[18] Beck AT, Ward CH, Mendelson M, Mock J, Erbaugh J. An inventory for measuring depression. Archives of General Psychiatry. 1961; 4: 561–571. https://doi.org/10.1001/archpsyc.1961.01710120031004

[19] Parmelee PA, Katz IR. Geriatric depression scale. Journal of the American Geriatrics Society. 1990; 38: 1379. https://doi.org/10.1111/j.1532-5415.1990.tb03461.x

[20] Annunziata MA, Muzzatti B, Bidoli E, Flaiban C, Bomben F, Piccinin M, et al. Hospital Anxiety and Depression Scale (HADS) accuracy in cancer patients. Supportive Care in Cancer. 2020; 28: 3921–3926. https://doi.org/10.1007/s00520-019-05244-8

[21] Lundin A, Möller J, Forsell Y. The Major Depression Inventory for diagnosing according to DSM-5 and ICD-11: Psychometric properties and validity in a Swedish general population. International Journal of Methods in Psychiatric Research. 2023; 32: e1966. https://doi.org/10.1002/mpr.1966

[22] Jenkinson C. The SF-36 physical and mental health summary measures: an example of how to interpret scores. Journal of Health Services Research & Policy. 1998; 3: 92–96. https://doi.org/10.1177/135581969800300206

[23] Sakman F. Calculated Decisions: Patient Health Questionnaire-9 (PHQ-9). Emergency Medicine Practice. 2019; 21: CD1–CD2.

[24] Tremblay MS, Warburton DER, Janssen I, Paterson DH, Latimer AE, Rhodes RE, et al. New Canadian physical activity guidelines. Applied Physiology, Nutrition, and Metabolism. 2011; 36: 36–46; 47–58. https://doi.org/10.1139/H11-009

[25] Jørgensen L, Paludan-Müller AS, Laursen DRT, Savović J, Boutron I, Sterne JAC, et al. Evaluation of the Cochrane tool for assessing risk of bias in randomized clinical trials: overview of published comments and analysis of user practice in Cochrane and non-Cochrane reviews. Systematic Reviews. 2016; 5: 80. https://doi.org/10.1186/s13643-016-0259-8

[26] De Luca R, Gangemi A, Maggio MG, Bonanno M, Calderone A, Mazzurco Masi VM, et al. Effects of Virtual Rehabilitation Training on Post-Stroke Executive and Praxis Skills and Depression Symptoms: A Quasi-Randomised Clinical Trial. Di-

agnostics. 2024; 14: 1892. https://doi.org/10.3390/diagnostics14171892

[27] Zhao L, Lyu X, Jiang H, Gao X. Musicokinetic and exercise therapies decrease the depression level of elderly patients undergoing post-stroke rehabilitation: The moderating effect of health regulatory focus. Frontiers in Psychology. 2022; 13: 889510. https://doi.org/10.3389/fpsyg.2022.889510

[28] Chippala P, Sharma R. Effect of Very Early Mobilisation on Symptoms of Depression and Anxiety Following Acute Stroke: A Randomised Controlled Trial. Journal of Clinical and Diagnostic Research. 2020; 2: YC01–YC05. https://doi.org/10.7860/JCDR/2020/37948.13486

[29] Vloothuis JDM, Mulder M, Nijland RHM, Goedhart QS, Konijnenbelt M, Mulder H, et al. Caregiver-mediated exercises with e-health support for early supported discharge after stroke (CARE4STROKE): A randomized controlled trial. PLoS ONE. 2019; 14: e0214241. https://doi.org/10.1371/journal.pone.0214241

[30] Cheng C, Liu X, Fan W, Bai X, Liu Z. Comprehensive Rehabilitation Training Decreases Cognitive Impairment, Anxiety, and Depression in Poststroke Patients: A Randomized, Controlled Study. Journal of Stroke and Cerebrovascular Diseases. 2018; 27: 2613–2622. https://doi.org/10.1016/j.jstrokecerebrovasdis.2018.05.038

[31] Faulkner J, McGonigal G, Woolley B, Stoner L, Wong L, Lambrick D. A randomized controlled trial to assess the psychosocial effects of early exercise engagement in patients diagnosed with transient ischaemic attack and mild, non-disabling stroke. Clinical Rehabilitation. 2015; 29: 783–794. https://doi.org/10.1177/0269215514555729

[32] Feng S, Zhang M, Dai Z. Effectiveness evaluation of rehabilitation for patients with post-stroke depression. Chinese Journal of Physical Medicine and Rehabilitation. 2003; 4: 39–41.

[33] Feng T, Zhao C, Dong J, Xue Z, Cai F, Li X, et al. The effect of unaffected side resistance training on upper limb function reconstruction and prevention of sarcopenia in stroke patients: a randomized controlled trial. Scientific Reports. 2024; 14: 25330. https://doi.org/10.1038/s41598-024-76810-2

[34] Vahlberg B, Cederholm T, Lindmark B, Zetterberg L, Hellström K. Short-term and long-term effects of a progressive resistance and balance exercise program in individuals with chronic stroke: a randomized controlled trial. Disability and Rehabilitation. 2017; 39: 1615–1622. https://doi.org/10.1080/09638288.2016.1206631

[35] Sims J, Galea M, Taylor N, Dodd K, Jespersen S, Joubert L, et al. Regenerate: assessing the feasibility of a strength-training program to enhance the physical and mental health of chronic post stroke patients with depression. International Journal of Geriatric Psychiatry. 2009; 24: 76–83. https://doi.org/10.1002/gps.2082

[36] Li M, Wang Q, Ma J, Meng P, Zhang D, Gong Y. The effect of intensive training on the lower limb motor function of post-stroke depression of stroke survivors. Chinese Journal of Physical Medicine and Rehabilitation. 2016; 38: 283–286. https://doi.org/10.3760/cma.j.issn.0254-1424.2016.04.010 (In Chinese)

[37] Zhao J, Chau JPC, Chan AWK, Meng Q, Choi KC, Xiang X, et al. Tailored Sitting Tai Chi Program for Subacute Stroke Survivors: A Randomized Controlled Trial. Stroke. 2022; 53: 2192–2203. https://doi.org/10.1161/STROKEAHA.121.036578

[38] Zhao B, Tang Q, Wang Y, Zhu LW, Yang HX, Ye T. Effects of Taijiquan on Motor Function and Depression in Patients with Post-stroke Depression. Chinese Journal of Rehabilitation Theory and Practice. 2017; 23: 334–337. https://doi.org/10.3969/j.issn.1006-9771.2017.03.019 (In Chinese)

[39] Chan W, Immink MA, Hillier S. Yoga and exercise for symptoms of depression and anxiety in people with poststroke disability: a randomized, controlled pilot trial. Alternative Therapies in Health and Medicine. 2012; 18: 34–43.

[40] Steen Krawcyk R, Vinther A, Petersen NC, Faber J, Iversen HK, Christensen T, et al. Effect of Home-Based High-Intensity Interval Training in Patients With Lacunar Stroke: A Randomized Controlled Trial. Frontiers in Neurology. 2019; 10: 664. https://doi.org/10.3389/fneur.2019.00664

[41] Bamalan OA, Moore MJ, Al Khalili Y. Physiology, Serotonin. In StatPearls [Internet]. StatPearls Publishing: Treasure Island, FL. 2025.

[42] Li C, Zhao M, Sun T, Guo J, Wu M, Li Y, et al. Treatment effect of exercise training on post-stroke depression in middle-aged and older adults: A meta-analysis. International Journal of Geriatric Psychiatry. 2022; 37: 10.1002/gps.5798. https://doi.org/10.1002/gps.5798

[43] Strawn JR, Mills JA, Suresh V, Peris TS, Walkup JT, Croarkin PE. Combining selective serotonin reuptake inhibitors and cognitive behavioral therapy in youth with depression and anxiety. Journal of Affective Disorders. 2022; 298: 292–300. https://doi.org/10.1016/j.jad.2021.10.047

[44] Pizzagalli DA, Roberts AC. Prefrontal cortex and depression. Neuropsychopharmacology. 2022; 47: 225–246. https://doi.org/10.1038/s41386-021-01101-7

[45] Ross RE, VanDerwerker CJ, Saladin ME, Gregory CM. The role of exercise in the treatment of depression: biological underpinnings and clinical outcomes. Molecular Psychiatry. 2023; 28: 298–328. https://doi.org/10.1038/s41380-022-01819-w

[46] Dunlap KR, Laskin GR, Waddell DS, Black AJ, Steiner JL, Vied C, et al. Aerobic exercise-mediated changes in the expression of glucocorticoid responsive genes in skeletal muscle differ across the day. Molecular and cellular endocrinology. 2022; 550: 111652. https://doi.org/10.1016/j.mce.2022.111652

[47] Garber CE, Blissmer B, Deschenes MR, Franklin BA, Lamonte MJ, Lee IM, et al. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. Medicine and Science in Sports and Exercise. 2011; 43: 1334–1359. https://doi.org/10.1249/MSS.0b013e318213fefb

[48] Wang ZY, Deng YL, Zhou TY, Jiang ZY, Liu Y, Liu BF, et al. The effects of exercise interventions on depressive symptoms in stroke patients: a systematic review and meta-analysis. Frontiers in Physiology. 2025; 16: 1492221. https://doi.org/10.3389/fphys.2025.1492221

[49] Aidar FJ, Jacó de Oliveira R, Gama de Matos D, Chilibeck PD, de Souza RF, Carneiro AL, et al. A randomized trial of the effects of an aquatic exercise program on depression, anxiety levels, and functional capacity of people who suffered an ischemic stroke. The Journal of Sports Medicine and Physical Fitness. 2018; 58: 1171–1177. https://doi.org/10.23736/S0022-4707.17.07284-X

[50] Chen R, Guo Y, Kuang Y, Zhang Q. Effects of home-based exercise interventions on post-stroke depression: A systematic review and network meta-analysis. International Journal of Nursing Studies. 2024; 152: 104698. https://doi.org/10.1016/j.ijnurstu.2024.104698

[51] Vetrovsky T, Fortova T, Conesa-Ros E, Steffl M, Heczkova J, Belohlavek J, et al. Increased Cardiopulmonary Fitness Is Associated with a Greater Reduction in Depression among People Who Underwent Bariatric Surgery. International Journal of Environmental Research and Public Health. 2021; 18: 2508. https://doi.org/10.3390/ijerph18052508