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Perturbation-based balance training for functional balance recovery and fall prevention in stroke patients: a systematic review and meta-analysis of randomized controlled trials

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People's Hospital.**ADMINISTRATIVE INFORMATION****Support** - None.**Review Stage at time of this submission** - Data analysis.**Conflicts of interest** - None declared.**INPLASY registration number:** INPLASY2026100102**Amendments** - This protocol was registered with the International Platform of Registered Systematic Review and Meta-Analysis Protocols (INPLASY) on 25 October 2026 and was last updated on 25 October 2026.**INTRODUCTION**

Review question / Objective • Population (P): Adult patients (aged ≥ 18 years) with clinically and radiologically diagnosed stroke (ischemic or hemorrhagic) in subacute or chronic recovery phases.

• Intervention (I): Perturbation-based balance training (PBT), defined as reactive balance training incorporating repeated, unexpected external mechanical perturbations (delivered via split-belt treadmills, movable balance platforms, robotic force-field systems, waist-pulls, or therapist manual perturbations) within a safety harness.

• Comparator (C): Active non-perturbation control interventions, including conventional physical therapy, voluntary weight-shifting, stretching, or unperturbed treadmill/overground gait training matched for training frequency, duration, and attention.

• Outcomes (O): Primary outcomes are functional balance assessed by the Berg Balance Scale (BBS, 0-56 points) and prospective real-world falls (fallers risk ratio [RR] and adjusted fall incidence

rate ratio [IRR/RaR]). Secondary outcomes include Activities-specific Balance Confidence (ABC, 0-100%), Timed Up and Go (TUG), 10-Meter Walk Test (10MWT), and adverse events (AEs).

• Study Design (S): Strictly randomized controlled trials (RCTs). Parallel-group and cross-over RCTs (pre-crossover data) are eligible.

Rationale Falls affect up to 73% of stroke survivors within the first year. Conventional physical therapy emphasizes voluntary, anticipatory balance, but real-world falls occur when unexpected slips or trips displace the center of mass, requiring automated, rapid reactive stepping (<150 ms) to avoid a fall. Perturbation-based balance training (PBT) repeatedly challenges stability to retrain reactive stepping reflexes. Previous meta-analyses (Alayat 2022; 7 RCTs, 271 patients) pooled disparate scales (BBS and Mini-BEST) into an SMD, included contaminated controls, and lacked pooling on prospective fall rates. Since 2022, multiple multicenter RCTs (Grevelding 2025, Krause 2024, Niewolak 2025) have emerged. An updated systematic review is

urgently required to resolve whether PBT genuinely slashes real-world falls and to determine whether efficacy differs between subacute and chronic stroke stages.

Condition being studied Stroke (ischemic or hemorrhagic stroke), acute, subacute, and chronic stroke survivors with motor impairment, postural instability, impaired reactive stepping reflexes, and heightened risk of falls.

METHODS

Search strategy #1 (Stroke[Mesh] OR "Cerebrovascular Disorders"[Mesh] OR "Brain Ischemia"[Mesh] OR stroke*[tiab] OR "cerebrovascular accident"[tiab] OR CVA*[tiab] OR hemipleg*[tiab] OR hemipar*[tiab])

#2 ("Postural Balance"[Mesh] OR perturbat*[tiab] OR "perturbation-based"[tiab] OR "reactive balance"[tiab] OR "reactive stepping"[tiab] OR "protective stepping"[tiab] OR slip*[tiab] OR trip*[tiab] OR "split-belt"[tiab] OR "force platform"[tiab])

#3 ("Randomized Controlled Trial" [Publication Type] OR randomized[tiab] OR randomised[tiab] OR randomly[tiab] OR trial[ti])

#4 #1 AND #2 AND #3

(Matched Emtree and topic terms are adapted for Embase and Web of Science).

Participant or population Adult patients (aged ≥ 18 years) with a clinically and neuroimaging-confirmed diagnosis of stroke (ischemic stroke or intracerebral hemorrhage) across all stages of post-stroke recovery (including subacute [≤ 6 months] and chronic [> 6 months] phases) presenting with motor hemiparesis, postural instability, balance impairments, or risk of falls, who are capable of participating in rehabilitation protocols.

Intervention Perturbation-based balance training (PBT, also termed perturbation-based reactive balance training), defined as physical rehabilitation protocols that expose participants to repeated, unexpected external mechanical perturbations (delivered via motorized split-belt treadmills, multidirectional movable balance platforms, robotic force-field error augmentation, waist-pull cable systems, or therapist-applied manual pushes and pulls) while secured in a safety harness. Training aims to repeatedly challenge postural stability at or near the threshold of falling to stimulate neuromuscular adaptation and recalibrate rapid compensatory stepping reflexes.

Comparator Active non-perturbation control interventions or conventional physical therapy (PT), including traditional voluntary balance training (e.g., voluntary weight-shifting, seated and standing reaching tasks), overground gait training, unperturbed steady-speed treadmill walking, or stretching and functional mobility exercises, matched for exercise frequency, session duration, total training dose, and therapist attention, without exposure to unexpected mechanical perturbations.

Study designs to be included Strictly randomized controlled trials (RCTs), including parallel-group RCTs and cross-over RCTs (only pre-cross-over phase data will be extracted and analyzed to eliminate carry-over effects). Non-randomized controlled trials, quasi-randomized trials, single-arm interventional studies, observational cohort studies, case reports, biomechanical descriptive studies without control groups, animal experiments, and review articles will be excluded.

Eligibility criteria Inclusion criteria:

1. Population: Adult patients (aged ≥ 18 years) with a clinically and neuroimaging-confirmed diagnosis of ischemic or hemorrhagic stroke in any post-stroke phase (subacute [≤ 6 months] or chronic [> 6 months]).
2. Intervention: Perturbation-based balance training (PBT) delivering repeated, unexpected external mechanical perturbations (via split-belt treadmills, movable platforms, robotic systems, or manual forces) in a safety harness.
3. Comparator: Active non-perturbation control interventions or conventional physical therapy (e.g., voluntary balance exercises, overground walking, or steady-speed treadmill gait) matched for training dosage and session duration.
4. Outcomes: Reporting at least one of the following validated outcomes: functional balance (Berg Balance Scale [BBS]), prospective real-world falls (fallers risk ratio, fall incidence rate ratio), balance confidence (Activities-specific Balance Confidence [ABC]), mobility (Timed Up and Go [TUG], 10-Meter Walk Test [10MWT]), or adverse events.
5. Study design: Strictly randomized controlled trials (parallel-group or pre-cross-over phase of cross-over RCTs).

Exclusion criteria:

1. Non-stroke neurological disorders (e.g., Parkinson's disease, spinal cord injury, traumatic brain injury, multiple sclerosis).
2. Interventions where both experimental and control arms received perturbation training (preventing PBT versus non-PBT efficacy evaluation).

3. Localized or joint-specific perturbation paradigms without whole-body postural balance or fall endpoints (e.g., isolated ankle perturbation devices).
4. Non-randomized clinical studies, single-arm pilot trials, observational cohort studies, case series, and narrative reviews.
5. Conference abstracts, protocol-only registrations, or studies with duplicate patient cohorts where usable numerical outcome data are unavailable.

Information sources Electronic databases to be searched:

1. PubMed / MEDLINE
2. Embase (via Ovid / Elsevier)
3. Web of Science (Core Collection)
4. Cochrane Central Register of Controlled Trials (CENTRAL)

Supplementary sources:

- Clinical trial registries (ClinicalTrials.gov, WHO International Clinical Trials Registry Platform [ICTRP], ISRCTN, and Chinese Clinical Trial Registry [ChiCTR]) to identify ongoing, completed, and unpublished trials.
- Backward and forward citation tracking of included studies, relevant clinical guidelines, and previous systematic reviews.

Search timeframe: From database inception through October 2026.

Restrictions: No language, publication year, or geographical restrictions are applied.

Main outcome(s) The review has two primary co-outcomes:

1. Functional Balance:

Assessed using the Berg Balance Scale (BBS, scoring range 0 to 56 points, higher scores indicate superior postural stability). Evaluated immediately post-intervention and synthesized as weighted Mean Differences (MD) with 95% confidence intervals against the established minimal clinically important difference (MCID = 4-5 points in stroke).

2. Prospective Real-World Fall Outcomes (Hard Clinical Endpoints):

(a) Real-World Fall Incidence Rate Ratio (IRR / RaR): Evaluated during prospective long-term follow-up (up to 12 months), accounting for individual person-year exposure duration and recurrent fall events, derived from multivariable negative binomial regression or generalized linear mixed models (GLMM) and synthesized as adjusted rate ratios via generic inverse-variance meta-analysis.

(b) Proportion of Fallers (Risk Ratio, RR): Evaluated as the binary risk of experiencing at least one fall during the prospective follow-up period.

Quality assessment / Risk of bias analysis

Methodological quality and risk of bias of all included randomized controlled trials will be independently appraised by two investigators using the revised Cochrane Risk of Bias tool for randomized trials (RoB 2) across five domains: (1) randomization process, (2) deviations from intended interventions, (3) missing outcome data, (4) measurement of the outcome, and (5) selection of the reported result. Discrepancies will be resolved through consensus or consultation with a third reviewer. Each domain and overall risk will be judged as "Low risk", "Some concerns", or "High risk". Risk of bias assessments and methodological quality summaries will be managed and plotted using Stata (StataNow 19.5 MP).

Strategy of data synthesis All statistical analyses and meta-analyses will be performed using Stata (StataNow 19.5 MP). For continuous outcomes (BBS, ABC) measured on identical scales, weighted Mean Differences (MD) with 95% confidence intervals will be pooled using random-effects restricted maximum likelihood (REML) models. For binary faller data, Risk Ratios (RR) will be synthesized. For prospective fall rate ratios accounting for person-year exposure and recurrent falls, log-transformed adjusted Incidence Rate Ratios (IRR/RaR) and standard errors will be pooled using generic inverse-variance random-effects meta-analysis. Heterogeneity will be evaluated using Cochran's Q test and the I^2 statistic. Subgroup analyses will be stratified by stroke chronicity (subacute [≤ 6 months] vs. chronic [> 6 months]). Leave-one-out sensitivity analyses and publication bias tests (Egger's and Begg's tests with funnel plots) will be executed in Stata.

Subgroup analysis Subgroup analyses will be stratified by post-stroke recovery phase:

1. Subacute Stroke (≤ 6 months from stroke onset, spontaneous neuroplastic recovery active);
2. Chronic Stroke (> 6 months from stroke onset, consolidated motor recovery plateau).

Sensitivity analysis Leave-one-out sensitivity analysis (omitting one trial at a time) will be executed to test the robustness of pooled estimates. Sensitivity analyses will also evaluate the impact of including trials with high risk of bias (Fan 2025) and median-converted scores (Esmaeili 2020).

Country(ies) involved China.

Keywords Stroke rehabilitation; Perturbation-based balance training; Fall prevention; Berg Balance Scale; Reactive stepping; Postural balance; Systematic review; Meta-analysis.

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