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Balance-Challenge Training over Low-Load Resistance for Squatting Deficits in Older Adults: A Meta-Analysis

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ADMINISTRATIVE INFORMATION

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Amendments - This protocol was registered with the International Platform of Registered Systematic Review and Meta-Analysis Protocols (INPLASY) on 2 December 2025 and was last updated on 2 December 2025.

INTRODUCTION

Review question / Objective As the global population ages, declining squatting capacity undermines older adults' functional independence and quality of life. While exercise is key for rehabilitation, a lack of standardized "squatting difficulty" definitions and unclear comparative efficacy of training modalities hinder targeted interventions. To address this, we first developed the Evidence-based Squatting Difficulty Scale (E-SDS) via systematic review for quantitative deficit identification.

Rationale With age-related declines in neuromuscular function, the prevalence of difficulty in performing the squatting task increases significantly among older adults. This functional impairment is not merely a matter of "slowness in rising"; rather, it often indicates underlying health conditions such as sarcopenia and frailty, and serves as a strong predictor of future functional decline and hospitalization risk. Therefore, developing and evaluating effective rehabilitation strategies to delay or improve Squatting ability in older adults is of considerable clinical and societal importance for promoting healthy aging.

Condition being studied Exercise rehabilitation has been widely established as a cornerstone intervention for improving lower limb strength and functional performance in older adults[6]. Numerous randomized controlled trials (RCTs) have explored the potential of various strategies—such as resistance training, balance training, Tai Chi, and multicomponent exercise—to improve Squatting capacity. However, substantial heterogeneity exists across these studies in terms of intervention protocols, duration, intensity, and the criteria used to define participants' functional levels, leading to considerable variability in research findings.

More critically, a fundamental methodological challenge in this field is the lack of a universally accepted and standardized quantitative definition for "Squatting difficulty." Most studies rely solely on qualitative descriptions (e.g., "self-reported difficulty in rising"), and this definitional ambiguity significantly limits the comparability across different studies. To address these issues, we first conducted a preliminary literature review to develop an evidence-based quantitative criterion for assessing and grading Squatting difficulty in older adults. This criterion was designed to capture the population with Squatting impairment as comprehensively as possible.

METHODS

Search strategy A comprehensive literature search was conducted to identify relevant randomized controlled trials (RCTs) published from January 2015 to October 2025. The search strategy was systematically developed around four core conceptual modules: (1) the older adult population, (2) squatting difficulty and associated functional impairments, (3) exercise-based rehabilitation strategies, and (4) high-quality study designs (RCTs). A logical expression, combining these modules with the Boolean operator "AND", was used to ensure the retrieval of studies focusing on the intersection of these concepts.

The final conceptual search expression was: ((older adults) AND (squatting difficulty) AND (exercise rehabilitation) AND (randomized controlled trial)).

The systematic search was performed across the following international and Chinese electronic databases: PubMed, Web of Science, the China National Knowledge Infrastructure (CNKI), and the Wanfang Data platform. The initial search yielded 3089 articles across all databases. Following this, a preliminary screening was performed to remove duplicates and any articles clearly identifiable as reviews or meta-analyses from their titles.

Participant or population

Participants: Community-dwelling or institutionalized older adults (mean age ≥ 60 years) with documented squatting difficulty or functional limitation. This was defined as either:

(I). Quantitative baseline performance below established age-appropriate norms (Table 1).

(II). A clinical diagnosis of sarcopenia or frailty.

(III). Explicit description of impaired mobility or functional limitations in the study's inclusion criteria.

Intervention Intervention: Supervised or unsupervised exercise-based rehabilitation (e.g., resistance, balance, functional, or multi-component training).

Comparator Comparison: Non-active control groups (e.g., usual care, waitlist, placebo, attention control, or other non-exercise interventions).

Study designs to be included The initial systematic search across the selected databases identified 3,089 potentially relevant articles. Following the import of all records into EndNote, 495 duplicates were identified and removed. the titles and abstracts of the remaining 2,594 records were screened, leading to the exclusion of 2,316 irrelevant studies. A full-text review was conducted for the remaining 246 articles to assess their eligibility based on the predefined inclusion and exclusion criteria. Finally, 16 studies were deemed eligible and included in the current systematic review and meta-analysis.

Eligibility criteria Studies were excluded for the following reasons:

(1) Study Design: Non-randomized controlled trials, including reviews, observational studies, and case reports. Studies published only as an abstract or with a total sample size of fewer than 30 participants were also excluded.

(2) Participants: Studies focusing on healthy, athletic older adults, or those where the functional impairment was attributable to acute conditions (e.g., recent stroke, major trauma) or comorbidities precluding safe exercise participation (e.g., severe dementia, uncontrolled cardiovascular disease).

(3) Intervention/Comparison: Non-exercise-based interventions (e.g., pharmacological, nutritional supplements alone). Trials with an intervention duration of less than 4 weeks, or those directly comparing two different active exercise regimens without a non-exercise control group, were also excluded from the primary analysis.

Information sources The systematic search was performed across the following international and Chinese electronic databases: PubMed, Web of Science, the China National Knowledge Infrastructure (CNKI), and the Wanfang Data platform. The initial search yielded 3089 articles across all databases. Following this, a preliminary screening was performed to remove duplicates and any articles clearly identifiable as reviews or meta-analyses from their titles.

Main outcome(s) We developed the Evidence-based Squatting Difficulty Scale (E-SDS) via systematic review for quantitative deficit identification. We then conducted a PRISMA-compliant systematic review and meta-analysis of RCTs (September 2015–September 2025) involving E-SDS-identified older adults, pooling data with a random-effects model. Analyzing 16 RCTs (1,594 participants), exercise interventions significantly improved the Timed Up and Go test (MD = –2.02 s; 95% CI: –2.81 to –1.23), 5-repetition Sit-to-Stand test (MD = –2.96 s; 95% CI: –5.45 to –0.46), and 30-Second Chair Stand Test (MD = +3.19 repetitions; 95% CI: 0.50 to 5.89). Subgroup analyses showed non-resistance training (NRT) outperformed resistance training (RT) in TUG and 5-rep STS ($p < 0.05$), with comparable efficacy in 30s-CST ($p = 0.94$). NRT benefited those with mild impairment, while moderate-to-severe deficits required higher-intensity interventions. In conclusion, exercise rehabilitation effectively mitigates squatting difficulties. NRT excels at improving dynamic balance/coordination, and both modalities enhance muscular endurance. E-SDS facilitates a shift to precision rehabilitation by aligning interventions with individual functional profiles.

Quality assessment / Risk of bias analysis The methodological quality of each included randomized controlled trial (RCT) was independently assessed by two reviewers using the revised Cochrane Risk-of-Bias tool (RoB 2.0). This tool evaluates five domains: the randomization p35rocess, deviations from intended interventions, missing outcome data, outcome measurement, and selection of reported results. Each study was judged to have a "low risk," "some concerns," or "high risk" of bias overall. Any disagreements between reviewers were resolved through consensus or by consulting a third author.

Strategy of data synthesis To ensure the accuracy and reproducibility of the screening process, literature identification and data extraction followed a systematic procedure. First, all records retrieved from the databases were imported into EndNote X21 (Clarivate Analytics, Philadelphia, PA, USA) to automatically identify and remove duplicates. Next, two reviewers independently screened the titles and abstracts of the remaining records against the eligibility criteria, guided by the PRISMA flow diagram. For records deemed potentially relevant, full-text articles were retrieved and subjected to a thorough secondary assessment based on the predefined inclusion and exclusion criteria. Finally, relevant data were extracted from the included studies and categorized according to their characteristics to facilitate subsequent qualitative synthesis and quantitative meta-analysis.

Subgroup analysis Data synthesis and statistical analysis were performed using Review Manager (RevMan, version 5.4, The Cochrane Collaboration). A random-effects model was employed for all meta-analyses (conducted when an outcome was reported in at least three studies) to account for anticipated clinical heterogeneity. Treatment effects for continuous outcomes are reported as standardized mean differences (MDs) with 95% confidence intervals (CIs).
Statistical heterogeneity was assessed using the I^2 statistic, interpreted as follows: low (50%). The Chi-square test was also consulted. Furthermore, for outcomes comprising more than ten studies, potential publication bias was explored through visual inspection of funnel plots.

Sensitivity analysis
To assess the robustness of the pooled effect sizes, sensitivity analyses were performed as follows:
1. Leave-one-out analysis: Each study was sequentially excluded, and the meta-analysis was repeated to evaluate the impact of individual studies on the overall results.
2. Subgroup analysis by study quality: Only studies with high methodological quality (Jadad score ≥ 4 or low risk of bias per ROB 2.0) were included for re-analysis.
3. Model switching: Pooled effect sizes were recalculated using a fixed-effect model (FEM) and compared with those from the random-effect model (REM) to examine the influence of heterogeneity.
4. Exclusion of studies with high missing data: Studies with missing data proportion > 20% were excluded, and the meta-analysis was repeated.
All sensitivity analyses were conducted using Stata 17.0 (StataCorp LP, College Station, TX, USA). The robustness of the conclusions was determined by comparing the direction, magnitude, and statistical significance (95% confidence interval [CI] and P value) of the pooled effect sizes across different analytical strategies.

Country(ies) involved China.

Keywords Squatting difficulty; Older adults; Meta-analysis; Precision rehabilitation; Evidence-based Squatting Difficulty Scale (E-SDS).

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