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EFFECTS OF SYMMETRY-TARGETED REHABILITATION AFTER TOTAL KNEE ARTHROPLASTY: A SYSTEMATIC REVIEW

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ABSTRACT
Persistent inter-limb loading asymmetry and compensatory movement patterns may remain after total knee arthroplasty (TKA) despite improvements in pain and conventional functional outcomes. Symmetry-targeted rehabilitation has been proposed to specifically address these residual deficits. To systematically evaluate the effects of symmetry-targeted rehabilitation and movement retraining after unilateral TKA on limb-loading symmetry, gait and functional mobility, muscle strength, and patient-reported outcomes. PubMed, Cochrane Library, and ScienceDirect were systematically searched from January 2010 to September 2026. Comparative studies evaluating rehabilitation explicitly targeting movement or loading symmetry after unilateral TKA were included. Risk of bias was assessed using RoB 2 for randomized trials and ROBINS-I for non-randomized studies. Findings were synthesized qualitatively. Of 329 records identified, 322 were excluded during title and abstract screening, and five studies involving 266 participants were included. Symmetry-targeted interventions included force-based biofeedback, balance-board training, therapist cueing, and wearable insole feedback. Improvements in direct weight-bearing symmetry were inconsistent. Some studies demonstrated improved knee-joint mechanics, greater operated-limb utilization, reduced contralateral compensation, or improved sit-to-stand performance, while most gait, strength, and patient-reported outcomes were comparable with conventional rehabilitation. Symmetry-targeted rehabilitation may be a useful adjunct after unilateral TKA, particularly for patients with persistent movement asymmetry, but current evidence does not demonstrate consistent superiority over conventional rehabilitation.

Keywords: biofeedback; movement symmetry; rehabilitation; total knee arthroplasty; weight-bearing

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INTRODUCTION

Total knee arthroplasty (TKA) is a surgical treatment for end-stage knee osteoarthritis and is increasingly performed as populations age and indications for surgery expand. Recent projections among Medicare beneficiaries in the United States indicate substantial growth in primary TKA utilization through 2040, emphasizing the growing importance of optimizing postoperative recovery rather than focusing solely on surgical success (Jones et al., 2025). Rehabilitation is a central component of this recovery process, with conventional programs commonly emphasizing pain control, restoration of range of motion, progressive strengthening, and recovery of basic functional mobility. However, systematic reviews have shown considerable heterogeneity among rehabilitation programs, broadly comparable improvements in pain, strength, range of motion, and activities of daily living (Konnyu et al., 2023).

One such impairment is the persistence of abnormal movement mechanics after otherwise successful TKA. Patients may continue to walk with reduced gait speed, altered stance characteristics, reduced single-limb support, and persistent abnormalities in knee and hip kinematics and kinetics beyond six months after surgery (Marino et al., 2024). The condition of the contralateral knee can influence gait symmetry after TKA, and altered postoperative biomechanics may be associated with contralateral osteoarthritis progression (Aljehani et al., 2022; Oshima & Majima, 2025). Moreover, perceived recovery may not fully reflect objective biomechanical recovery, highlighting the need to interpret symmetry together with movement quality (Hopkins et al., 2026).

Symmetry-targeted rehabilitation has therefore emerged as a strategy to directly address compensatory movement behavior, such as visual or auditory biofeedback, force or pressure sensing, therapist cueing, balance and weight-shifting exercises, and task-specific retraining. Recent randomized evidence, however, has produced mixed findings. A pilot Physical Activity and Symmetry intervention did not demonstrate clinically meaningful improvements in loading symmetry compared with an attention-control intervention, despite improvements occurring over time in both groups (Queen et al., 2024). Similarly, a larger randomized trial of movement-pattern biofeedback found no improvement in the primary outcome of surgical-limb peak knee extension moment, although reduced contralateral loading suggested that targeted training could modify certain compensatory movement strategies (Bade et al., 2025). Contemporary physical therapy guidelines continue to emphasize progressive rehabilitation after TKA, but the specific contribution of movement-symmetry retraining to recovery remains less clearly established than conventional impairment-based rehabilitation components (Bove et al., 2026).

Existing reviews of rehabilitation after TKA have predominantly evaluated broad categories of postoperative exercise and rehabilitation rather than examining symmetry-targeted rehabilitation as a distinct therapeutic concept (Konnyu et al., 2023). A synthesis focused specifically on these interventions is therefore needed to determine whether deliberate retraining of inter-limb loading provides benefits beyond conventional rehabilitation and whether biomechanical improvements translate into meaningful functional recovery. Accordingly, this systematic review aimed to evaluate the effects of symmetry-targeted rehabilitation and movement retraining compared with conventional postoperative rehabilitation in adults following unilateral TKA.

METHOD

Search Strategy

A systematic literature search was conducted in PubMed, the Cochrane Library, and ScienceDirect to identify studies evaluating symmetry-targeted rehabilitation or movement retraining following unilateral total knee arthroplasty (TKA). The search covered all records from January 2010 to September 2026. Search terms were constructed around three principal concepts: total knee arthroplasty, movement or loading symmetry/biofeedback, and postoperative rehabilitation. No MeSH terms or title/abstract field restrictions were applied. The exact PubMed search strategy was: ("total knee arthroplasty" OR "total knee replacement") AND (biofeedback OR "movement symmetry" OR "loading symmetry" OR "weight-bearing symmetry") AND (rehabilitation OR physiotherapy OR "physical therapy"). The exact Cochrane Library search strategy was: ("total knee arthroplasty" OR "total knee replacement") AND (biofeedback OR "movement symmetry" OR "loading symmetry") AND (rehabilitation OR "physical therapy"). The exact ScienceDirect search strategy was: "total knee arthroplasty" AND (biofeedback OR "movement symmetry" OR "loading symmetry") AND (rehabilitation OR "physical therapy").

Eligibility Criteria

Studies were eligible if they included adults undergoing unilateral primary TKA and compared a postoperative rehabilitation intervention explicitly targeting loading or movement symmetry with conventional or attention-control rehabilitation. Eligible outcomes included limb loading, movement mechanics, gait or mobility, muscle strength, and patient-reported function. Randomized and prospective comparative interventional studies were included.

Studies without an explicit symmetry-targeted intervention, separable unilateral TKA data, a comparator group, or sufficient outcome data were excluded, as were reviews, protocols, case reports, conference abstracts, observational biomechanical studies, and non-human studies.

Study Selection

All records identified from the three databases were initially screened by title and abstract for relevance to the review question. Records clearly unrelated to unilateral TKA rehabilitation, symmetry retraining, or movement/loading biofeedback were excluded. Potentially relevant records were subsequently assessed for duplication, after which the remaining full-text articles were evaluated against the predefined eligibility criteria. The study-selection process was documented using a PRISMA flow diagram.

Data Extraction

Data were extracted using a standardized extraction framework developed according to the review objectives. Extracted study characteristics included author and publication year, study design, participant characteristics and sample size, details of the symmetry-targeted intervention, comparator rehabilitation protocol, and duration of follow-up. Outcome data were extracted for measures of limb-loading and weight-bearing symmetry, gait biomechanics and functional mobility, muscle strength, and patient-reported outcomes. Measures of joint loading, including knee extension moments, vertical ground-reaction-force symmetry, weight-bearing ratios, and limb symmetry indices, were extracted when reported. Functional outcomes included walking speed, Six-Minute Walk Test, Timed Up and Go, sit-to-stand tests, stair-climbing performance, and other study-specific mobility assessments. Strength, range-of-motion, pain, functional questionnaires, and health-related quality-of-life outcomes were also extracted where available. The main direction and clinical interpretation of each study's findings were summarized in a single consolidated characteristics-and-results table.

Risk of Bias Assessment

The methodological quality of the included studies was evaluated according to study design. Randomized controlled trials were assessed using the Cochrane Risk of Bias 2 tool (RoB 2). Each randomized study was classified according to the RoB 2 framework as having low risk of bias, some concerns, or high risk of bias. The non-randomized prospective comparative study was evaluated using the Risk Of Bias In Non-randomized Studies of Interventions (ROBINS-I) tool. The overall risk of bias was determined according to the judgments across these domains.

Data Synthesis

Because of substantial clinical and methodological heterogeneity in the symmetry-targeted interventions, outcome definitions, biomechanical measurement techniques, and timing of follow-up, the findings were synthesized qualitatively rather than quantitatively. Results were grouped into four principal outcome domains: limb-loading and movement symmetry, gait and functional mobility, muscle strength, and patient-reported outcomes.

RESULT

Study Selection

The database search identified 329 records, comprising 41 records from PubMed, 26 from the Cochrane Library, and 262 from ScienceDirect. Following title and abstract screening, 322 records were excluded, leaving seven potentially eligible records. One duplicate was identified and removed, resulting in six articles undergoing full-text assessment. One full-text article was excluded because of inappropriate participant characteristics. Ultimately, five studies fulfilled the eligibility criteria and were included in the qualitative synthesis.

Characteristics of Included Studies

The five included studies were published between 2013 and 2026 and collectively enrolled 266 participants, with individual study sample sizes ranging from 20 to 138 participants. Four studies used randomized controlled designs, including one pragmatic pilot trial and one feasibility trial, whereas one study was a prospective longitudinal cohort with a matched comparison group. (Figure 1)

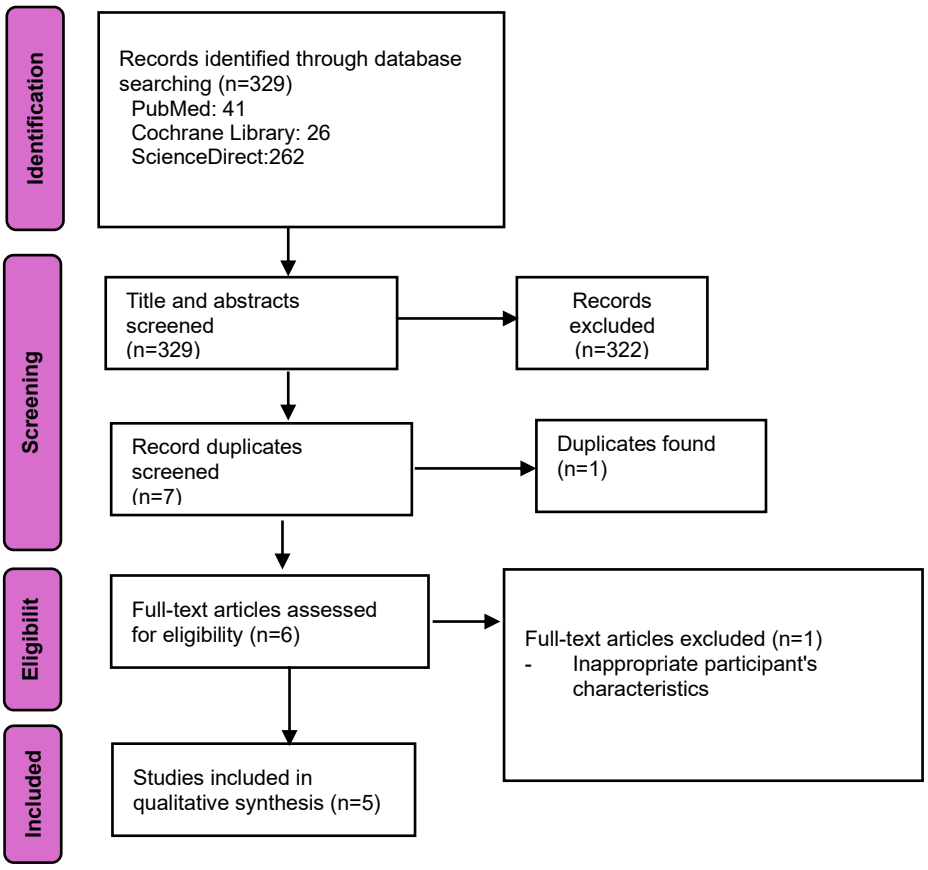


Figure 1. Diagram flow of literature search strategy for this systematic review

The overall risk of bias was considered low across the four randomized controlled trials, with low-risk judgments in all RoB 2 domains, including randomization, deviations from the intended interventions, missing outcome data, outcome measurement, and selective reporting. The non-randomized study by Zeni et al. (2013) was judged to have a moderate overall risk of bias under ROBINS-I, primarily because of potential residual confounding, although the remaining domains were rated as low risk. Overall, the methodological quality of the included evidence was acceptable; however, findings from the non-randomized study should be interpreted with greater caution.

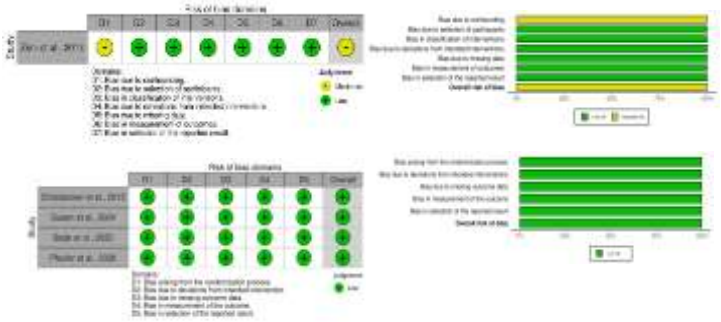


Figure 2. Risk of bias assessment results of the included studies

The symmetry-targeted interventions varied in their mode and intensity. Zeni et al. incorporated progressive symmetry retraining using visual, auditory, and tactile feedback, including bilateral leg-press feedback with the SymSlide and weight-distribution feedback with a Wii Balance Board. Christiansen et al. used six weeks of weight-bearing biofeedback during bilateral stance, weight shifting, sit-to-stand, unilateral stance, and lunging. Queen et al. evaluated a Physical Activity and Symmetry program combining physical activity counseling with balance and equal-loading exercises. Bade et al. used the MOVE program, which incorporated real-time Loadsol insole feedback and therapist cueing during walking, sit-to-stand, stair negotiation, and other functional activities. Pfeufer et al. evaluated a home-based Loadsol insole intervention consisting of 15 minutes of real-time biofeedback walking per day for four weeks. Follow-up periods ranged from two weeks to six months after TKA.

Outcome

Effects on direct measures of limb-loading symmetry were inconsistent. Zeni et al. reported greater vertical ground-reaction-force and knee-moment symmetry after targeted training, whereas Christiansen et al. and Queen et al. found no significant between-group improvement in weight-bearing or limb-symmetry measures. Bade et al. similarly found no improvement in surgical-limb peak knee extension moment, although contralateral knee loading was reduced. Pfeufer et al. observed improvement in loading rate in both groups without a significant between-group difference. More on Table 1.

Functional outcomes generally improved over time in both intervention and control groups, with few consistent between-group differences. Zeni et al. reported more symmetrical knee kinematics and sagittal knee moments during gait, with a greater six-minute walk distance in the symmetry-training group at six months, although Timed Up and Go and Stair Climb Test results were similar between groups. Christiansen et al. found significantly greater improvement in Five Times Sit-to-Stand performance and surgical-limb knee extension moment with biofeedback, while walking speed showed only a non-significant trend. In contrast, Queen et al., Bade et al., and Pfeufer et al. found no consistent superiority of symmetry-targeted rehabilitation in walking speed, stair-climbing, gait performance, or other functional mobility outcomes.

Effects on muscle strength and patient-reported outcomes were limited. Zeni et al. reported greater quadriceps symmetry and knee flexion range of motion after symmetry retraining, while Knee Outcome Survey scores were similar between groups. Queen et al. found no significant between-group differences in KOOS domains, although kinesiophobia improved more in the symmetry-focused group. Bade et al. and Pfeufer et al. reported no significant between-group differences in quadriceps strength or patient-reported functional and quality-of-life outcomes.

Table 1.
Characteristics and results of the included studies

Outcomes Study	Country; design	Sample and unit of analysis	Rehabilitation context	Comparator	Outcome assessment / follow-up
Zeni et al. (2013)	Country not reported; prospective longitudinal cohort with matched comparison group	22 unilateral TKA patients; symmetry training n=11, standard care n=11	Standard outpatient PT plus progressive symmetry retraining using visual, auditory, and tactile feedback, SymSlide, and Wii Balance Board	Standard outpatient PT without specific symmetry retraining	Pre-TKA, PT discharge/≈3 months, and 6 months
Christiansen et al. (2015)	Country not reported; randomized controlled trial with blinded evaluators	26 unilateral TKA patients; RELOAD n=13, control n=13	Standard rehabilitation plus 6-week weight-bearing biofeedback using Wii Balance Board	Dose-matched standard rehabilitation without symmetry-focused biofeedback	Preoperative, 6 weeks, and 26 weeks
Queen et al. (2024)	Country not reported; pragmatic pilot randomized controlled trial	60 post-TKA patients; PAS n=30, attention control n=30	Physical Activity and Symmetry program added to routine PT	Routine PT plus attention-matched sessions	≈3 and 6 months
Bade et al. (2025)	Country not reported; two-arm parallel randomized controlled trial	138 unilateral primary TKA patients; MOVE n=68, control n=70	Standardized rehabilitation plus movement-pattern retraining with real-time Loadsol insole biofeedback	Standardized rehabilitation without movement-pattern feedback	Preoperative, 10 weeks, and 6 months
Pfeufer et al. (2026)	Country not reported; prospective randomized controlled feasibility trial	20 enrolled; 18 included in final analysis; feedback n=8, routine care n=10	Standard physiotherapy plus home-based Loadsol insole biofeedback for 15 min/day over 4 weeks	Conventional physiotherapy alone	2 and 6 weeks post-TKA

DISCUSSION

This review found that symmetry-targeted rehabilitation after unilateral TKA can modify selected biomechanical movement patterns, although improvements in weight-bearing symmetry and conventional functional outcomes were inconsistent. Early feasibility findings were favorable, while subsequent randomized trials showed more heterogeneous effects (Christiansen et al., 2015; Zeni et al., 2013). More recent trials similarly showed that movement-pattern training could reduce compensatory loading of the contralateral knee even when surgical-limb loading, gait speed, strength, or patient-reported function were not superior to conventional rehabilitation (Bade et al., 2025; Pfeufer et al., 2026; Queen et al., 2024). These findings suggest that the principal effect of symmetry-targeted rehabilitation may lie in modifying how movement is performed.

Queen et al. (2024), and Pfeufer et al. (2025) found no significant advantage in weight-bearing, limb-symmetry, or loading-rate measures. Persistent postoperative asymmetry may nevertheless remain clinically relevant, as patients can continue to offload the operated limb beyond one year after TKA (Almonroeder et al., 2023). Changes in knee extension moments may be more informative than symmetry indices alone. Christiansen et al. found increased surgical-limb knee extension moments despite unchanged weight-bearing symmetry, while Bade et al. reported reduced contralateral knee loading without improvement in the primary surgical-limb knee moment (Bade et al., 2025). These results indicate that rehabilitation may alter the internal strategy used to accomplish a task without substantially changing gross limb loading.

Functional outcomes were generally less responsive to symmetry-targeted training than biomechanical variables. The included studies showed improvements over time in walking tests, sit-to-stand performance, stair negotiation, and Timed Up and Go, but most between-group differences were small or absent. An exception was the Christiansen trial, in which Five Times Sit-to-Stand performance improved significantly with biofeedback at both six and 26 weeks (Christiansen et al.,

2015). In contrast, the larger MOVE trial did not demonstrate superior six-month gait speed, Six-Minute Walk Test, Timed Up and Go, or 30-second sit-to-stand performance, while some early functional outcomes transiently favored the control group (Bade et al., 2025). Recent evidence has similarly shown that patient-reported and performance-based improvements correlate only incompletely with objective gait biomechanics after TKA (Hopkins et al., 2026). Thus, absence of a superior TUG, walking speed, or questionnaire score does not necessarily indicate that movement retraining failed to modify postoperative motor behavior.

The timing, intensity, and specificity of the interventions may also explain the heterogeneous findings. Biofeedback exposure also differed substantially, from integration throughout outpatient rehabilitation to only 15 minutes of daily home walking for four weeks. A recent systematic review of smartphone applications and wearable devices in postoperative TKA rehabilitation reported potential benefits for recovery and care adherence, while encompassing varied technologies and rehabilitation approaches (Gordon et al., 2025). The present review suggests that the therapeutic effect of symmetry-targeted feedback may depend on task specificity, sufficient training intensity, progressive adjustment, and the extent to which new movement patterns become habitual.

Patient selection may be equally important. Several included studies enrolled patients after unilateral TKA without requiring a predefined degree of persistent asymmetry before randomization. Consequently, some participants may already have demonstrated relatively symmetrical loading or rapidly improving movement patterns, leaving limited scope for additional benefit. This may partly explain why the PAS intervention improved neither loading symmetry nor physical function beyond the attention-control condition, and why the authors suggested that future interventions may be more appropriate for patients who continue to exhibit loading deficits after routine rehabilitation (Queen et al., 2024). A deficit-based approach may therefore be preferable to universally prescribing symmetry retraining. Objective screening of operated-to-contralateral loading, joint moments, or task-specific movement patterns could identify patients who continue to rely disproportionately on the non-operated limb and are consequently more likely to benefit from targeted retraining.

The findings also have implications for the role of symmetry within postoperative rehabilitation. Conventional TKA rehabilitation remains effective for improving pain, range of motion, muscle strength, and overall mobility (Bade et al., 2025; Bove et al., 2026; Konnyu et al., 2023), and the present evidence does not support replacing these components with symmetry training. Instead, movement retraining may be better viewed as an additional component for patients. This distinction is important because the clinical objective should aim to increase appropriate use of the operated limb, reduce excessive contralateral compensation, and restore efficient movement without creating new compensatory strategies. Objective gait or loading measures may therefore complement conventional performance tests to achieve satisfactory movement recovery.

Several limitations should be considered. Only five studies were included, with substantial heterogeneity in sample size, intervention characteristics, follow-up, and biomechanical outcome definitions, which precluded quantitative pooling. Several studies were pilot or feasibility trials, and one used a non-randomized comparative design. Follow-up was generally limited to six months, restricting conclusions about the durability of movement changes and potential effects on contralateral joint health. In addition, using the contralateral limb as a reference may be problematic in the presence of contralateral osteoarthritis or compensatory adaptations. Future studies should standardize biomechanical outcomes, report baseline asymmetry, stratify patients by movement deficits, and include longer follow-up.

CONCLUSION

Symmetry-targeted rehabilitation after unilateral total knee arthroplasty may improve selected biomechanical aspects of postoperative movement, particularly operated-limb use, knee joint mechanics, and compensatory loading of the contralateral limb. However, its effects on direct measures of weight-bearing symmetry, gait performance, muscle strength, and patient-reported outcomes remain inconsistent compared with conventional rehabilitation. Current evidence suggests that symmetry retraining may be most useful as an adjunctive, deficit-specific strategy rather than a universal replacement for standard postoperative rehabilitation.

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Declaration of the Use of Artificial Intelligence in Scientific Writing: Artificial intelligence tools were used to assist with language editing, and improving the clarity the manuscript. All AI-assisted content was reviewed and edited by the authors, who take full responsibility for the accuracy, integrity, and final content of the manuscript.

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