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SYSTEMATIC REVIEW Open Access

Changes in knee outcome measures following later-stage exercise interventions implemented ≤ 12 weeks vs. > 12 weeks after total knee arthroplasty: a systematic review and meta-analysis

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Abstract

Background Later-stage exercise interventions refer to rehabilitation exercises implemented after the initial healing phase. Following total knee arthroplasty (TKA), patients generally begin these high-intensity exercises at the 2-month mark. Nevertheless, the duration of these exercise programs varies across studies, and the extent to which later-stage exercises contribute to improvements in the knee outcome measures over time remains unclear. This study aims to systematically evaluate the changes in the knee outcome measures following later-stage exercise interventions implemented at ≤ 12 weeks versus > 12 weeks after TKA.

Methods The PubMed, Scopus, and Web of Science databases were searched through May 2025 to identify the randomized controlled trials evaluating the effects of later-stage exercise interventions on the knee outcome measures. The certainty of evidence was assessed using the Grading of Recommendations Assessment, Development, and Evaluation approach. Additionally, the completeness of the intervention descriptions was evaluated using the Template for Intervention Description and Replication checklist. A subgroup analysis was conducted to compare the outcomes of interventions lasting ≤ 12 weeks with those lasting > 12 weeks. Moreover, the minimal detectable change (MDC) values were referenced to interpret the clinical relevance of the observed changes.

Results Fifteen studies involving 1,160 TKA patients were included. Across all studies, the sit-to-stand performance was observed to be enhanced by 2.61 s or 2.7 repetitions; the stair climbing duration decreased by 3.35 s; the knee flexor strength increased by 3.36 kg-force; and the knee extension angle reduced by 3.96°. For interventions ≤ 12 weeks, the timed up-and-go improved by 2.78 s. For interventions > 12 weeks, the knee extensor strength increased by 15.59 kg-force, and the knee flexion angle improved by 14.40°. The certainty of evidence ranged from low to moderate, and the intervention descriptions demonstrated moderate completeness.

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Conclusion Many observed changes in the knee outcome measures exceeded the MDC thresholds, indicating clinically meaningful benefits from later-stage exercise interventions post-TKA. The interventions implemented at ≤ 12 weeks primarily improved the functional performance, whereas those lasting > 12 weeks resulted in greater gains in the muscle strength and joint flexibility. Stronger evidence and more detailed intervention descriptions are needed to better integrate these findings into rehabilitation practice.

Keywords Knee arthroplasty, Exercise, Outcome assessment, Functional performance, Muscle strength

Background

Total knee arthroplasty (TKA) is a widely performed surgical procedure used for managing knee osteoarthritis. In the United Kingdom, approximately 100,000 to 200,000 TKA procedures are conducted annually [1, 2]. The global incidence of TKA has steadily increased over the past decade [3], consequently resulting in more than 4.5 million individuals currently living with a TKA implant [4, 5]. Research has consistently demonstrated that TKA effectively reduces pain and disability in individuals with knee osteoarthritis [6–9]. In addition to surgery, factors such as intra-articular injections [10], patellofemoral joint disease [11], multimodal analgesia [12], and subchondral bone and inflammatory phenotypes [13] notably affect the TKA outcomes.

Although most patients can resume daily activities following surgery, their performance often remains lower compared to that of age- and sex-matched healthy individuals [14, 15]. Postoperative complications such as joint swelling and scar tissue adherence may restrict the knee's range of motion [16, 17]. Some patients continue to experience knee function impairments, such as a 41% reduction in the knee extensor strength, which contributes to a 28% decrease in the walking distance and a 105% increase in the time required to climb stairs [18, 19]. Therefore, postoperative rehabilitation is crucial for restoring function and mobility after TKA.

In TKA rehabilitation, exercise is typically initiated shortly after surgery to promote early recovery. Early-stage exercise interventions are often introduced before hospital discharge to enhance mobility and reduce pain [19–24]. Early rehabilitation following TKA is well-documented and supported by previous reviews [20, 21, 25]; however, many studies highlight the importance of continuing the exercises beyond this stage [26, 27]. High-intensity and full weight-bearing exercises are also generally impractical during this early stage due to inflammation and the ongoing healing process [28, 29]. A key knowledge gap remains in terms of the exercise interventions implemented after early-stage rehabilitation.

Later-stage exercises refer to the rehabilitation exercises introduced after the healing phase to restore knee function through a more intensive training [28, 30]. To ensure patient compliance, studies commonly require that patients undergo TKA at least 2 months prior [28, 31], placing them beyond the early-stage rehabilitation period when the surgical wound has healed, and the artificial joint has stabilized [28, 31]. Nonetheless, the duration of later-stage programs can remarkably vary across clinical settings and studies, with some protocols concluding within 12 weeks and others extending beyond this period. In exercise intervention research, a 12-week duration is often used as the threshold for distinguishing short-term (≤ 12 weeks) from long-term (> 12 weeks) programs [32]. Recent evidence has notably indicated a lack of consensus regarding the extent of improvement in the knee outcome measures during the later stages of rehabilitation, particularly when comparing the program durations (≤ 12 weeks vs. > 12 weeks) initiated after 2 months post-TKA.

In clinical practice, implementing exercise programs is often challenging because of the inadequate reporting of interventions. Hoffman et al. (2014) emphasized the importance of specifying key features such as duration, intensity, delivery mode, and monitoring procedures [33]. For clarity enhancement, the Template for Intervention Description and Replication (TIDieR) checklist encourages authors to include the key intervention details for replication and clinical application [34]. Hence, this study aims to systematically evaluate the changes in the knee outcome measures following later-stage exercise interventions, comparing those implemented within ≤ 12 weeks to those implemented after > 12 weeks. Additionally, the certainty of the evidence and the completeness of the intervention descriptions were also assessed. The obtained findings may help clarify the role of later-stage exercise in improving the knee outcome measures over time and further inform evidence-based clinical practice.

Methods

This study followed the Preferred Reporting Items for Systematic Reviews and Meta-analysis statement [35] and was registered on the International Prospective Register of Systematic Reviews (PROSPERO) under the identifier CRD42023438253 with the following title: "*The impact of later-stage exercise interventions on clinical outcomes in patients with total knee arthroplasty: a systematic review and meta-analysis of randomized controlled trials.*"

Any disagreements between the two primary reviewers (PK and KS) throughout the review process were resolved through a consensus. When a consensus could not be achieved, a third independent reviewer (RV) was consulted for the final decision.

Data sources and search strategy

A comprehensive search was conducted in the PubMed, Scopus, and Web of Science databases from inception to May 2025 (Supplementary Material 1). Duplicate records were removed using EndNote 20 (Clarivate Analytics, Boston, USA).

Selection criteria

PK and KS independently evaluated randomized controlled trials for eligibility (Table 1). Studies were briefly selected based on the following PICO criteria: (P) patients who had undergone TKA at least 2 months prior to initiating the later-stage exercise intervention; (I) any type of exercise administered without being combined with other treatment modalities; (C) an intervention duration of either ≤ 12 or > 12 weeks; (O) objective or subjective outcomes relevant to the knee outcome measures. Note that only studies published in English were included in this review.

Data extraction

Two independent reviewers (PK and KS) extracted and summarized the following information from each study: first author's name and publication year; sample size, age, and surgical details; description and dosage of the exercise interventions; and outcomes relevant to the knee outcome measures.

Risk of bias

The risk of bias was evaluated using the Physiotherapy Evidence Database (PEDro) scale [36, 37]. The PEDro scores were obtained from the database. For unrated studies, reviewers PK and KS assigned the scores. The PEDro scores ranged from 0 to 10: scores of 8–10 indicated low risk; scores of 6–7 indicated good quality; scores of 4–5 indicated moderate risk; and scores below 4 indicated high risk. Studies that scored below 4 were considered at risk of bias [36, 37].

Table 1 Eligibility criteria based on the Population, Intervention, Comparison, and Outcome (PICO) framework

Criteria	Description
P, population	Individuals who have undergone total knee arthroplasty and reached a postoperative period of at least two months (or eight weeks)
I, intervention	Any type of later-stage exercise at any dosage, including supervised or home-based programs. Later-stage exercise interventions are defined as rehabilitation exercises implemented after two months post-surgery. Studies were excluded if the exercise was combined with other treatment modalities
C, comparison	Later-stage exercise interventions implemented for ≤ 12 weeks or > 12 weeks
O, outcome	*Objective outcomes*: functional performance, muscle strength, range of motion, or other variables related to knee outcome measures *Subjective outcomes*: pain intensity, disability score, mental status, or other patient-reported variables related to knee outcome measures

Completeness of the intervention descriptions

The TIDieR checklist comprised 12 items (Supplementary Material 2) [33]. Each study was independently assessed by two reviewers (PK and KS) using the TIDieR checklist to identify missing or adequately reported items [34]. The scores were converted into percentages and categorized as follows: < 50%, poor; 51 to 79%, moderate; and > 80%, good level of description [38, 39].

Result synthesis

The results were synthesized using Review Manager version 5.4 (RevMan, Copenhagen, Denmark), with p-values < 0.05 considered statistically significant. Only the outcomes reported in at least three studies were included in the synthesis [35]. The comparable outcomes were normalized and converted to consistent measurement scales. The mean difference with 95% confidence intervals (95% CI) was calculated.

The changes in the knee outcome measures following different exercise durations in later stages were examined by performing subgroup analyses to compare studies with interventions implemented at ≤ 12 weeks with those implemented at > 12 weeks. The minimal detectable change (MDC) values for each outcome measure were referenced from previous studies to assist in the interpretation of the clinical relevance of the observed changes.

The heterogeneity was assessed using the I2 statistic, with values exceeding 50% indicating substantial heterogeneity. The potential sources of variability among studies were explored through sensitivity analyses. Furthermore, only studies with a PEDro score ≥ 4 were included in the meta-analysis. A random-effects model was applied to account for between-study heterogeneity.

Certainty of evidence assessments

The certainty of evidence was assessed using the Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) approach [40]. Two reviewers PK and KS independently assessed the evidence and had the discretion to downgrade its certainty to moderate, low, or very low based on the following five GRADE domains: 1) risk of bias; 2) inconsistency; 3) indirectness; 4) imprecision; 5) publication bias (assessed via Egger's regression test) [41].

Results

Search results

The three databases initially yielded 3,247 studies. In addition, one more study [42] was manually identified from Google using the same keywords as the search strategy (Fig. 1). After duplicate removal, 1,951 studies remained. Following the title and abstract screening, 125 studies were selected for a full-text review. Of these, 15 studies were found to meet the eligibility criteria and were included in the analysis [28, 30, 42–54].

Study characteristics

The bias scores for the 12 studies [30, 42, 44, 45, 47–54] were obtained from the PEDro database. Three studies [28, 43, 46] were rated by independent reviewers (PK and KS). The PEDro scores ranged from 2 to 8 points, averaging 6.07 ± 1.79, which indicated a low-to-moderate risk of bias (Supplementary Material 3). The sensitivity analysis identified two studies [46, 51] with a high risk of bias (PEDro scores < 4). The validity of the pooled results was ensured by excluding these studies from the meta-analysis.

The 15 studies were published between 2003 and 2023. A total of 1,160 patients with TKA were recruited and included in the systematic review, while 1,122 patients were included in the meta-analysis. The included studies on the exercise interventions comprised a combination of home-based and supervised exercises, with 53% combining both settings [28, 30, 42–44, 49, 50, 52], 20% focusing solely on home-based exercises [45, 51, 54], and 27% exclusively using supervised exercises [46–48, 53]. The exercises were categorized by purpose as follows: strengthening exercises to enhance the muscle strength; functional training for functional performance; stretching exercises to increase the muscle length; range of motion exercises for joint mobility; endurance training for cardiopulmonary fitness; and balance training for postural control (Table 2).

Both durations primarily focused on strengthening exercises, with 100% of the interventions lasting ≤ 12 weeks and 83% of those lasting > 12 weeks; however, interventions lasting ≤ 12 weeks more often included functional training as a secondary component (78%), whereas those with durations > 12 weeks more likely incorporated stretching exercises (67%) (Supplementary Material 4).

The TIDieR checklist scores for the included studies ranged from 58 to 75%, averaging 66 ± 5%, indicating moderate completeness in the exercise intervention descriptions (Supplementary Material 5). Nevertheless, most studies did not report on key aspects such as implementation, monitoring, and modification.

Changes in functional performance following the later-stage exercise

Five-times sit-to-stand test: Eight studies [30, 42, 43, 47, 48, 50, 52, 53] involving 466 TKA patients evaluated the five-times sit-to-stand test. The interventions ≤ 12 weeks showed a remarkable reduction in the duration of 2.78 s [42, 53] ($p < 0.01$; I2: 37%), whereas interventions > 12 weeks showed no remarkable change ($p = 0.45$) [30, 50]. The overall analysis found a reduction of 2.61 s [30, 42, 50, 53] ($p < 0.01$, I2: 46%; Fig. 2A). The test for the subgroup differences was nonsignificant ($p = 0.70$; Table 3), and no substantial publication bias was detected

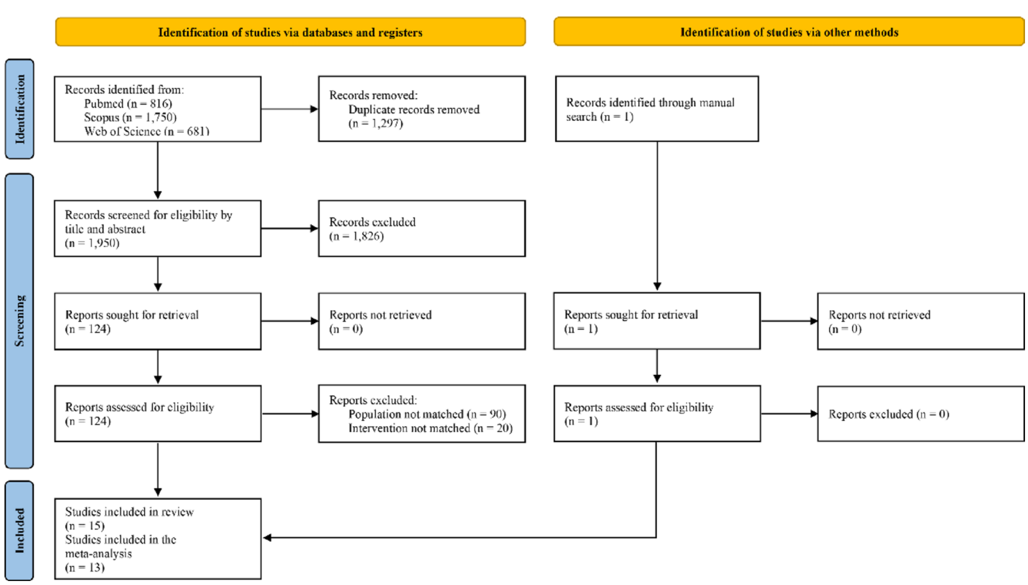

Fig. 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram summarizing the study screening and selection for review

Table 2 Summary of the fifteen included studies

Study	Population	Exercise intervention			Outcomes	
		Descriptions	**Dosage**	**TIDieR score (0 – 100)**	**Significant changes**	**No significance**
[43]	N: 32 Age: 64.31 ± 5.03 Time since surgery: ≥ 3 months Operated leg: Unilateral leg Primary TKA: Yes Surgical method identification: Yes	*Supervised and home-based exercise:* 1) Strengthening exercises - Knee extensor - Hip abductor - Hip adductor 2) Functional training - Walking 3) Stretching exercises - Knee flexor - Ankle plantar-flexor	50 min./session 2 sessions/wk 8 wk	75	*Objective outcomes:* 1) Functional performance - Chair stand test↑ - 9-steps stair climbing test↓ 2) Gait parameter - Maximum walking speed↑ 3) Knee muscle strength - Knee extensor↑ - Hip abductor↑ 4) Knee range of motion - Knee flexion angle↑ - Knee extension angle↓ *Subjective outcomes:* 1) Pain intensity - VAS↓ 2) Disability score - WOMAC↓ - FJS-12↑ - WHOQOL-BREF(Physical)↑ 3) Mental status - WHOQOL-BREF(Psychologic)↑	
[42]	N: 55 Age: 72.80 ± 5.47 Time since surgery: ≥ 3 months Operated leg: Unilateral and bilateral legs Primary TKA: N/A Surgical method identification: N/A	*Supervised and home-based exercise:* 1) Strengthening exercises - Knee extensor - Hip flexor - Hip extensor - Hip abductor - Hip adductor - Hip external rotator 2) Range of motion exercises - Knee flexion - Knee extension	> 10 min./session 3 sessions/wk 12 wk	58	*Objective outcomes:* 1) Functional performance - 5-times sit-to-stand test↓ - Timed up-and-go test↓ - Single-leg stance test↑ - 8-reps alternative step test↓ 2) Gait parameter - Normal walking speed↑ - 6-min walk test↑ - Single support time↑ - Double support time↓ 3) Knee range of motion - Knee flexion angle↑ - Knee extension angle↓ *Subjective outcomes:* 1) Disability score - WOMAC↓	*Objective outcomes:* 1) Gait parameter - Stride length

Table 2 (continued)

Study	Population	Exercise intervention			Outcomes	
		Descriptions	Dosage	TIDieR score (0 – 100)	Significant changes	No significance
[44]	N: 334 Age: 67.50 ± 9.46 Time since surgery: ≥ 2 months Operated leg: N/A Primary TKA: Yes Surgical method identification: N/A	*Supervised and home-based exercise:* 1) Strengthening exercises - Knee flexor - Knee extensor - Hip abductor 2) Functional training - Sit-to-stand - Stair climbing - Walking - Stepping - Squatting 3) Stretching exercises - Knee flexor - Knee extensor - Ankle plantar-flexor 4) Range of motion exercises - Knee flexion Knee extension - Ankle plantar-flexion - Ankle dorsi-flexion 5) Endurance training - Treadmill walking - Stationary cycling 6) Balance training - Single-leg stance - Standing on foam and tilt board - Side stepping - Cross-over steps - Tandem walk - Braiding balance - Shuttle walk - Multidirectional walk	60 min./session 3 sessions/wk 6 wk	67	*Subjective outcomes:* 1) Disability score - Oxford knee score↑	*Objective outcomes:* 1) Functional performance - Timed up-and-go test *Subjective outcomes:* 1) Pain intensity - VAS
[45]	N: 50 Age: 69.00 ± 8.00 Time since surgery: ≥ 2 months Operated leg: Unilateral and bilateral legs Primary TKA: Yes Surgical method identification: Yes	*Home-based exercise:* 1) Strengthening exercises - Knee flexor - Knee extensor 2) Functional training - Sit-to-stand - Stepping - Squatting 3) Stretching exercises - Knee flexor - Knee extensor - Hip flexor - Ankle plantar-flexor	> 10 min./session 2 sessions/wk 52 wk	75	*Objective outcomes:* 1) Gait parameter - Maximum walking speed↑ - Cadence (maximum speed)↑ 2) Knee muscle strength - Knee flexor↑	*Objective outcomes:* 1) Gait parameter - Normal walking speed - Cadence (normal speed) 2) Knee muscle strength - Knee extensor *Subjective outcomes:* 1) Pain intensity - VAS

Table 2 (continued)

Study	Population	Exercise intervention			Outcomes	
		Descriptions	**Dosage**	**TIDieR score (0 – 100)**	**Significant changes**	**No significance**
[46]	N: 14 Age: 72.00 ± 1.80 Time since surgery: ≥ 3 months Operated leg: Unilateral leg Primary TKA: Yes Surgical method identification: N/A	*Supervised exercises:* 1) Strengthening exercises - Knee flexor - Knee extensor - Hip extensor - Hip adductor	> 60 min./session 3 sessions/wk 24 wk	67	*Objective outcomes:* 1) Functional performance - Chair stand test↑ 2) Gait parameter - 6-min walk test↑ 3) Knee muscle strength - Knee flexor↑ - Knee extensor↑ - Hip extensor↑ *Subjective outcomes:* 1) Disability score - KOOS↑	*Objective outcomes:* 1) Functional performance - Timed up-and-go test 2) Knee muscle strength - Hip flexor
[48]	N: 113 Age: 72.13 ± 6.93 Time since surgery: ≥ 2 months Operated leg: Unilateral leg Primary TKA: Yes Surgical method identification: Yes	*Supervised exercises:* 1) Strengthening exercises - Knee flexor - Knee extensor - Hip abductor 2) Functional training - Sit-to-stand - Stair climbing - Walking 3) Stretching exercises - Knee flexor - Knee extensor - Ankle plantar-flexor - Ankle dorsi-flexor 4) Range of motion exercises - Knee flexion - Knee extension - Ankle plantar-flexion - Ankle dorsi-flexion 5) Endurance training - Treadmill walking - Stationary cycling 6) Balance training - Standing on foam and tilt board - Side stepping - Cross-over steps - Tandem walk - Multidirectional walk	> 60 min./session 3 sessions/wk 8 wk	67	*Objective outcomes:* 1) Functional performance - Chair stand test↑ - Timed up-and-go test↓ - Single-leg stance test ↑ - 4-steps stair climbing test↓ - Functional reach test↑ 2) Gait parameter - Normal walking speed↑ *Subjective outcomes:* 1) Disability score - WOMAC↓	

Table 2 (continued)

Study	Population	Exercise intervention			Outcomes	
		Descriptions	**Dosage**	**TIDieR score (0 – 100)**	**Significant changes**	**No significance**
[47]	N: 130 Age: 72.41 ± 6.68 Time since surgery: ≥ 2 months Operated leg: Unilateral leg Primary TKA: Yes Surgical method identification: Yes	*Supervised exercises:* 1) Strengthening exercises - Knee flexor - Knee extensor - Hip abductor 2) Functional training - Sit-to-stand - Stair climbing - Walking 3) Stretching exercises - Knee flexor - Knee extensor - Ankle plantar-flexor - Ankle dorsi-flexor 4) Range of motion exercises - Knee flexion - Knee extension - Ankle plantar-flexion - Ankle dorsi-flexion 5) Endurance training - Treadmill walking - Stationary cycling 6) Balance training - Standing on foam and tilt board - Side stepping - Cross-over steps - Tandem walk - Multidirectional walk	> 60 min./session 3 sessions/wk 8 wk	67	*Objective outcomes:* 1) Functional performance - Chair stand test↑ - Timed up-and-go test↓ - Single-leg stance test ↑ - 4-steps stair climbing test↓ - Functional reach test↑ 2) Gait parameter - Normal walking speed↑ *Subjective outcomes:* 1) Disability score - WOMAC↓	
Study	**Population**	**Exercise intervention**			**Outcomes**	
		Descriptions	**Dosage**	**TIDieR score (0 – 100)**	**Significant changes**	**No significance**
[49]	N: 38 Age: 66.70 ± 8.70 Time since surgery: ≥ 2 months Operated leg: Unilateral leg Primary TKA: Yes Surgical method identification: N/A	*Supervised and home-based exercise:* 1) Strengthening exercises - Knee flexor - Knee extensor - Hip abductor 2) Functional training - Sit-to-stand - Stair climbing - Walking 3) Stretching exercises - Knee flexor - Knee extensor - Ankle plantar-flexor - Ankle dorsi-flexor 4) Range of motion exercises - Knee flexion - Knee extension - Ankle plantar-flexion - Ankle dorsi-flexion 5) Endurance training - Treadmill walking - Stationary cycling	> 60 min./session 2 sessions/wk 6 wk	67	*Objective outcomes:* 1) Gait parameter - 6-min walk test↑ *Subjective outcomes:* 1) Disability score - WOMAC↓	*Subjective outcomes:* 1) Disability score - SF-36(PCS) 2) Mental status - SF-36(MCS)

Table 2 (continued)

Study	Population	Exercise intervention			Outcomes	
		Descriptions	**Dosage**	**TIDieR score (0 – 100)**	**Significant changes**	**No significance**
[50]	N: 35 Age: 68.45 ± 7.94 Time since surgery: ≥ 2 months Operated leg: Unilateral leg Primary TKA: N/A Surgical method identification: Yes	*Supervised and home-based exercise:* 1) Strengthening exercises - Knee flexor - Knee extensor - Hip extensor - Hip abductor 2) Functional training - Sit-to-stand - Stair climbing 3) Stretching exercises - Knee extensor - Knee flexor - Ankle plantar-flexor 4) Range of motion exercises - Knee flexion - Knee extension - Ankle plantar-flexion - Ankle dorsi-flexion 5) Endurance training - Treadmill walking - Stationary cycling 6) Balance training - Single-leg stance - Standing on foam and tilt board - Side stepping - Cross-over steps - Tandem walk - Braiding balance - Shuttle walk - Multidirectional walk	> 60 min./session 2 sessions/wk 24 wk	67	*Objective outcomes:* 1) Functional performance - 5-times sit-to-stand test↓ - Single-leg stance↑ 2) Gait parameter - Normal walking speed↑ *Subjective outcomes:* 1) Pain intensity - VAS↓ 2) Disability score WOMAC↓ - LEFS↑	
[30]	N: 20 Age: 68.30 ± 5.50 Time since surgery: ≥ 3 months Operated leg: Unilateral leg Primary TKA: N/A Surgical method identification: Yes	*Supervised and home-based exercise:* 1) Strengthening exercises - Knee flexor - Knee extensor - Hip extensor - Hip abductor 2) Stretching exercises - Knee extensor - Knee flexor - Ankle plantar-flexor 3) Range of motion exercises - Knee flexion - Knee extension - Ankle plantar-flexion - Ankle dorsi-flexion 4) Endurance training - Treadmill walking - Stationary cycling	> 60 min./session 2 sessions/wk 24 wk	58	*Objective outcomes:* 1) Functional performance - Single-leg stance↓ 2) Gait parameter - Normal gait speed↑ - 6-min walk test↑ *Subjective outcomes:* 1) Disability score - WOMAC↓ - SF-36(PCS)↑	*Objective outcomes:* 1) Functional performance - 5-times sit-to-stand test - 11-step stair climbing test

Table 2 (continued)

Study	Population	Exercise intervention			Outcomes	
		Descriptions	**Dosage**	**TIDieR score (0 – 100)**	**Significant changes**	**No significance**
[28]	N: 177 Age: 69.50 ± 6.50 Time since surgery: ≥ 2 months Operated leg: Unilateral leg Primary TKA: Yes Surgical method identification: N/A	*Supervised and home-based exercise:* 1) Strengthening exercises - Knee flexor - Knee extensor - Hip extensor - Hip abductor 2) Functional training - Walking - Stepping - Squatting 3) Endurance training - Treadmill walking - Stationary cycling	60 min./session 2 session/wk 12 wk	67	*Subjective outcomes:* 1) Disability score - WOMAC↓ - COPM↓	*Subjective outcomes:* 1) Disability score - PROMIS - SF-36(PCS)
[51]	N: 24 Age: 64.50 ± 8.20 Time since surgery: ≥ 10 months Operated leg: N/A Primary TKA: N/A Surgical method identification: N/A	*Home-based exercise:* 1) Endurance training - Treadmill walking - Stationary cycling	> 20 min./session 3 sessions/wk 16 wk	58	*Objective outcomes:* 1) Gait parameter - 6-min walk test↑ 2) Knee muscle strength - Knee extensor↑ 3) Knee range of motion - Knee extension angle↓ 4) Vital sign - Systolic blood pressure↓ - Diastolic blood pressure↓ 5) Anthropometrics - Sum of skinfolds↓ - Waist to hip↓ *Subjective outcomes:* 1) Disability score - WOMAC↓ - SF-36(PCS)↑	*Objective outcomes:* 1) Knee range of motion - Knee flexion angle 2) Vital sign - Heart rate 3) Anthropometrics - Body weight - Body mass index *Subjective outcomes:* 1) Mental status - SF-36(MCS)
[52]	N: 60 Age: 69.66 ± 7.25 Time since surgery: ≥ 48 months Operated leg: Bilateral leg Primary TKA: Yes Surgical method identification: Yes	*Supervised and home-based exercise:* 1) Strengthening exercises - Knee flexor - Knee extensor - Hip extensor - Hip abductor - Ankle plantar-flexor 2) Stretching exercises - Knee flexor - Knee extensor - Ankle plantar-flexor 3) Range of motion exercises - Knee flexion - Knee extension - Ankle plantar-flexion - Ankle dorsi-flexion	> 10 min./session 7 sessions/wk 8 wk	67	*Objective outcomes:* 1) Functional performance - Chair stand test↑ 2) Gait parameter - Normal gait speed↑ 3) Knee muscle strength - Knee flexor↑ - Knee extensor ↑ 4) Knee range of motion - Knee flexion↑ *Subjective outcomes:* 1) Pain intensity - VAS↓ 2) Disability score - HSS↑	

Table 2 (continued)

Study	Population	Exercise intervention			Outcomes	
		Descriptions	Dosage	TIDieR score (0 – 100)	Significant changes	No significance
[53]	N: 25 Age: 65.80 ± 6.20 Time since surgery: ≥ 4 months Operated leg: Unilateral leg Primary TKA: Yes Surgical method identification: Yes	*Supervised exercises:* 1) Strengthening exercises - Knee flexor - Knee extensor - Hip flexor - Hip extensor - Hip abductor - Hip adductor 2) Functional training - Walking - Jogging - Squatting	> 30 min./session 2 sessions/wk 12 wk	67	*Objective outcomes:* 1) Functional performance - 10-step stair-climbing test↓ - 10-times sit-to-stand test↓ 2) Gait parameter - Normal gait speed↑ 3) Knee muscle strength - Knee flexor↑ - Knee extensor↑ 4) Muscle cross-sectional area - Thigh muscles↑	*Objective outcomes:* 1) Gait parameter - Maximum gait speed *Subjective outcomes:* 1) Pain intensity - VAS 2) Disability score - WOMAC
[54]	N: 53 Age: 69.00 ± 8.00 Time since surgery: ≥ 2 months Operated leg: Unilateral leg Primary TKA: Yes Surgical method identification: Yes	*Home-based exercise:* 1) Strengthening exercises - Knee flexor - Knee extensor 2) Functional training - Stepping - Squatting 3) Stretching exercises - Knee flexor - Knee extensor - Hip flexor - Ankle plantar-flexor	> 10 min./session 2 sessions/wk 52 wk	67	*Objective outcomes:* 1) Gait parameter - Maximum gait speed↑ 2) Knee muscle strength - Knee flexor↑ *Subjective outcomes:* 1) Disability score - WOMAC↓ - SF-36(PCS)↑ 2) Mental status - SF-36(MCS)↑	*Objective outcomes:* 1) Functional performance - Timed up-and-go test 2) Knee muscle strength - Knee extensor 3) Knee range of motion - Knee flexion - Knee extension

COPM, Canadian Occupational Performance Measure; FJS-12, Forgotten Joint Score-12; HSS, Hospital for Special Surgery; KOOS, Knee Injury and Osteoarthritis Outcome Score; LEFS, Lower Extremity Functional Scale; N/A, Not Applicable; PROMIS, Patient-Reported Outcomes Measurement Information System; SF-36(MCS), 36-Item Short Form Health Survey Questionnaire (Mental Health Component Summary); SF-36(PCS), 36-Item Short Form Health Survey Questionnaire (Physical Component Summary); TIDieR, Template for Intervention Description and Replication; TKA, Total Knee Arthroplasty; VAS, Visual Analogue Scale; WHOQOL-BREF, World Health Organization Quality of Life Instrument; WOMAC, Western Ontario and McMaster University Osteoarthritis Index

($p = 0.32$). Notably, the observed improvement exceeded the MDC value of 1.7 s [55].

Chair stand test: Four studies [43, 47, 48, 52] reported a marked increase of 2.70 repetitions for interventions ≤ 12 weeks ($p < 0.01$; I2: 0%; Fig. 2B). No subgroup analysis was applicable for this outcome (Table 3), and no publication bias was detected ($p = 0.69$). The improvement also exceeded the MDC of one repetition [56].

Timed up-and-go test: Five studies [42, 44, 47, 48, 54] involving 637 TKA patients were analyzed for the timed up-and-go test. For interventions ≤ 12 weeks, four studies [42, 44, 47, 48] revealed marked duration reductions of 2.78 s ($p < 0.01$; I2: 67%). For interventions > 12 weeks, one study [54] reported a reduction of 1.58 s ($p < 0.01$). The overall analysis found a marked decrease of 2.59 s [42, 44, 47, 48, 54] ($p < 0.01$; I2: 74%; Fig. 2C). The subgroup analysis indicated that interventions ≤ 12 weeks showed greater improvement compared with interventions > 12 weeks ($p = 0.02$; Table 3). The observed decrease in duration exceeded the MDC of 1.1 s [57]. However, Egger's test revealed a substantial publication bias ($p = 0.04$), and the certainty of evidence was rated as very low (Table 4). The high heterogeneity of this outcome should be noted because it may have influenced the findings.

Stair climbing test: Four studies [30, 43, 47, 48] involving 295 TKA patients evaluated the stair climbing test, with steps ranging from 4 to 11. For interventions ≤ 12 weeks,

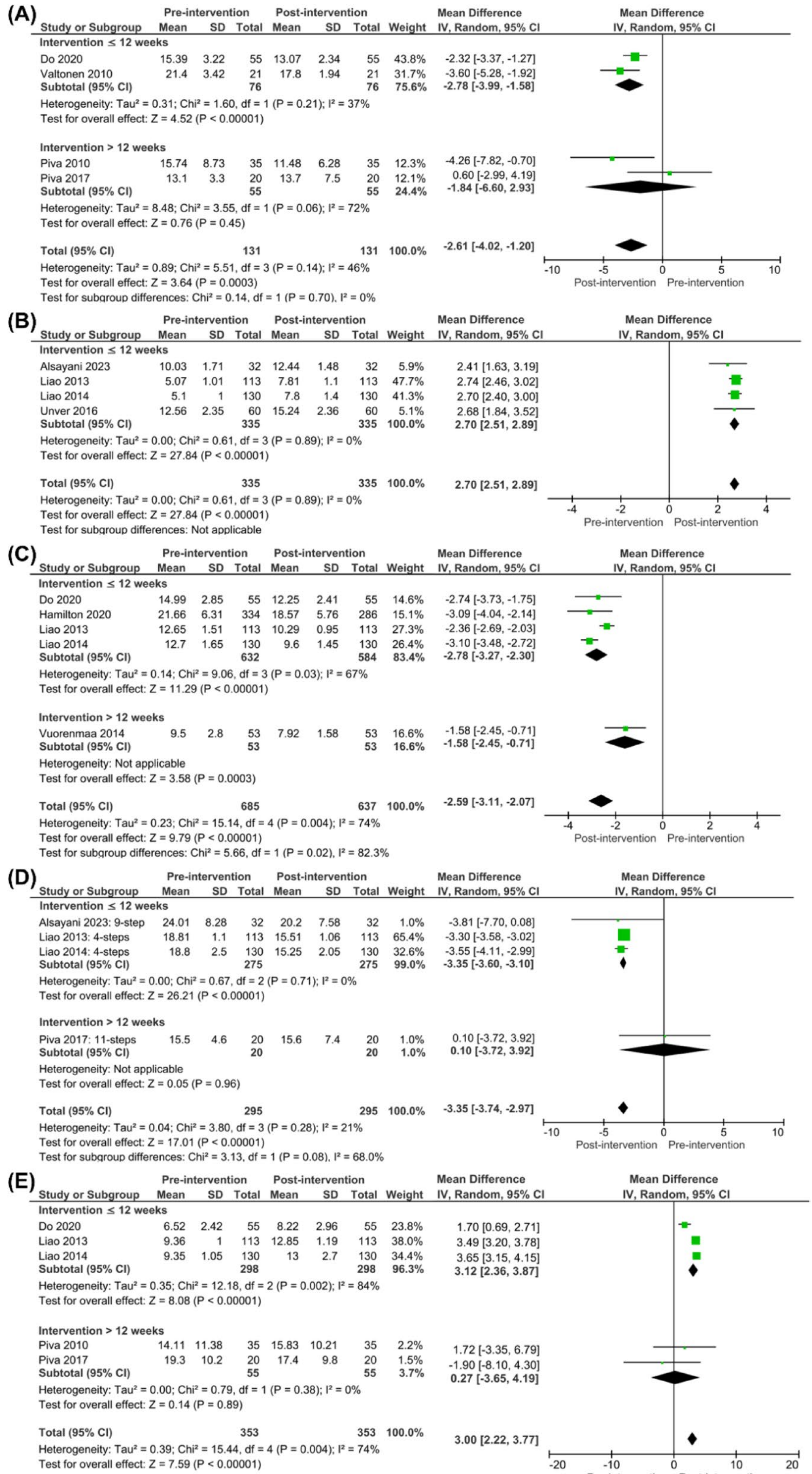

Fig. 2 Forest plots showing mean differences with 95% confidence intervals for changes in functional performance following later-stage exercise interventions: **A** five-times sit-to-stand test; **B** chair stand test; **C** timed up-and-go test; **D** stair climbing test; and **E** single-leg stance test

Table 3 Summary of knee outcome measures following later-stage exercise interventions implemented ≤ 12 weeks vs. > 12 weeks

	Later-stage exercise interventions				
Outcomes	**Overall**	**≤ 12 weeks**	**> 12 weeks**	**Subgroup differences**	**MDC[a]**
Objective outcomes					
Functional performance					
Five-times sit-to-stand test	−2.61 (−4.02 to −1.20)	−2.78 (−3.99 to −1.58)	−1.84 (−6.60 to 2.93)	0.70	**−1.70**[c]
Chair stand test	2.70 (2.51 to 2.89)	2.70 (2.51 to 2.89)	–	N/A	**1.00**[c]
Timed up-and-go test	−2.59 (−3.11 to −2.07)	−2.78 (−3.27 to −2.30)	−1.58 (−2.45 to −0.71)	**0.02**[b]	**−1.10**[c]
Stair climbing test	−3.35 (−3.74 to −2.97)	−3.35 (−3.60 to −3.10)	0.10 (−3.72 to 3.92)	0.08	**−0.20**[c]
Single-leg stance test	3.00 (2.22 to 3.77)	3.12 (2.36 to 3.87)	0.27 (−3.65 to 4.19)	0.16	19.00
Gait parameter					
Walking normal speed	0.18 (0.08 to 0.27)	0.22 (0.11 to 0.33)	0.10 (−0.01 to 0.21)	0.12	0.36
Walking maximum speed	0.22 (0.12 to 0.33)	0.14 (0.02 to 0.27)	0.32 (0.21 to 0.43)	**0.03**[b]	0.36
Walking distance	52.95 (23.29 to 82.61)	52.95 (23.29 to 82.61)	–	N/A	79.00
Muscle strength					
Knee flexor	3.36 (0.77 to 5.95)	1.76 (−0.81 to 4.33)	4.67 (3.38 to 5.96)	0.05	**2.50**[c]
Knee extensor	7.03 (2.75 to 11.32)	1.57 (0.73 to 2.40)	15.59 (12.39 to 18.78)	**< 0.01**[b]	**2.50**[c]
Range of motion					
Knee flexion angle	7.90 (3.66 to 12.15)	5.42 (3.19 to 7.66)	14.40 (9.17 to 19.63)	**< 0.01**[b]	7.90
Knee extension angle	−3.96 (−6.44 to −1.47)	−2.90 (−5.01 to −0.79)	−5.90 (−7.98 to −3.82)	0.05	**−3.80**[c]
Subjective outcomes					
Pain intensity	−1.04 (−1.62 to −0.47)	−1.18 (−1.93 to −0.43)	−0.72 (−1.19 to −0.25)	0.31	−2.80
Disability score	−15.59 (−24.12 to −7.06)	−17.18 (−27.43 to −6.93)	−10.40 (−19.77 to −1.02)	0.34	−19.00
Mental status	4.57 (2.29 to 6.85)	5.19 (1.90 to 8.49)	4.00 (0.85 to 7.15)	0.61	15.00

Values represent mean differences (95% confidence intervals). Values in bold indicate a change

MDC, minimal detectable change

[a] Minimal detectable change value from previous studies

[b] Statistical significance between subgroup differences

[c] Changes exceeding the minimal detectable change value

three studies [43, 47, 48] showed marked duration reductions of 3.35 s ($p < 0.01$; I2: 0%). Interventions > 12 weeks showed no marked improvement [30] ($p = 0.96$). The overall analysis found a marked reduction of 3.35 s [30, 43, 47, 48] ($p < 0.01$; I2: 21%; Fig. 2D). The test for the subgroup differences was nonsignificant ($p = 0.08$; Table 3), and no significant publication bias was detected ($p = 0.37$). The reduction exceeded the MDC of 0.2 s [58].

Single-leg stance test: Five studies [30, 42, 47, 48, 50] involving 353 TKA patients assessed the single-leg stance duration. For interventions ≤ 12 weeks, three studies [42, 47, 48] demonstrated a marked increase in duration of 3.12 s ($p < 0.01$; I2: 84%). For interventions > 12 weeks, two studies [30, 50] reported no remarkable change ($p = 0.89$). The overall analysis found a marked increase in duration of 3.00 s [30, 42, 47, 48, 50] ($p < 0.01$; I2: 74%; Fig. 2E). The subgroup differences were nonsignificant ($p = 0.16$; Table 3), and no publication bias was detected ($p = 0.82$). However, the observed increase did not meet the MDC of 19 s [59]. The high heterogeneity in this outcome may be because balance is not the primary focus for patients with TKA as most studies did not emphasize balance training. Consequently, the balance assessments used may not have been sensitive enough to detect changes, consequently leading to substantial heterogeneity in the results.

Changes in the gait parameter following later-stage exercise

Normal walking speed: Eleven studies [30, 42, 43, 45, 47–50, 52–54] involving 604 TKA patients examined the walking performance. The overall analysis of the normal walking speed from eight studies [30, 42, 45, 47, 48, 50, 52, 53] showed a notable improvement of 0.18 m/s ($p < 0.01$; I2: 94%; Fig. 3A). Interventions ≤ 12 weeks resulted in a marked increase of 0.22 m/s [42, 47, 48, 52, 53] ($p < 0.01$; I2: 95%), while those lasting > 12 weeks showed no marked change ($p = 0.07$) [30, 45, 50]. The subgroup difference was nonsignificant ($p = 0.12$; Table 3). Egger's test indicated no publication bias ($p = 0.67$). However, the improvements did not exceed the MDC of 0.36 m/s [55], suggesting that the clinical impact may be limited. The high heterogeneity observed in the obtained results suggests a substantial variability in the outcomes across the studies, which may be attributed to the differences in the assessment methods.

Maximum walking speed: The maximum walking speed analysis showed a marked increase of 0.22 m/s [43, 45, 53, 54] ($p < 0.01$; I2: 59%; Fig. 3B). No publication bias was

Table 4 Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) evidence for assessing the certainty of evidence

Outcomes	Risk of bias	Inconsistency	Indirectness	Imprecision	Publication bias	Number of patients		Overall certainty of evidence
						Pre	Post	
Objective outcomes								
Functional performance								
Five-times sit-to-stand test	Not serious	Not serious	Not serious	Serious[c]	No	131	131	⊕⊕⊕◯ Moderate
Chair stand test	Serious[a]	Not serious	Not serious	Serious[c]	No	335	335	⊕⊕◯◯ Low
Timed up-and-go test	Serious[a]	Serious[b]	Not serious	Not serious	Suspected[d]	685	637	⊕◯◯◯ Very low
Stair climbing test	Not serious	Not serious	Not serious	Serious[c]	No	295	295	⊕⊕⊕◯ Moderate
Single-leg stance test	Not serious	Serious[b]	Not serious	Serious[c]	No	353	353	⊕⊕◯◯ Low
Gait parameter								
Walking normal speed	Not serious	Serious[b]	Not serious	Not serious	No	491	488	⊕⊕⊕◯ Moderate
Walking maximum speed	Not serious	Serious[b]	Not serious	Serious[c]	No	163	160	⊕⊕◯◯ Low
Walking distance	Serious[a]	Not serious	Not serious	Serious[c]	No	113	113	⊕⊕◯◯ Low
Muscle strength								
Knee flexor	Not serious	Serious[b]	Not serious	Serious[c]	No	189	186	⊕⊕◯◯ Low
Knee extensor	Not serious	Serious[b]	Not serious	Serious[c]	No	221	218	⊕⊕◯◯ Low
Range of motion								
Knee flexion angle	Serious[a]	Serious[b]	Not serious	Serious[c]	No	224	224	⊕◯◯◯ Very low
Knee extension angle	Serious[a]	Serious[b]	Not serious	Serious[c]	No	140	140	⊕◯◯◯ Very low
Subjective outcomes								
Pain intensity	Not serious	Serious[b]	Not serious	Not serious	No	539	536	⊕⊕⊕◯ Moderate
Disability score	Serious[a]	Serious[b]	Not serious	Not serious	No	1,087	1,072	⊕⊕◯◯ Low
Mental status	Serious[a]	Not serious	Not serious	Serious[c]	No	123	123	⊕⊕◯◯ Low

MD, mean differences; 95%CI, 95% confidence intervals; MCD, minimal detectable change

[a] Some studies had a Physiotherapy Evidence Database (PEDro) Scale score of < 4

[b] An $I^2 > 50\%$

[c] A sample size of < 400 patients

[d] Suspicion raised by funnel plot and Egger's regression tests analysis

detected ($p = 0.89$). For interventions ≤ 12 weeks, a significant increase of 0.14 m/s was observed [43, 53] ($p < 0.01$; I2: 42%). For interventions > 12 weeks, the increase was 0.32 m/s [45, 54] ($p < 0.01$; I2: 0%). The subgroup analysis indicated that interventions > 12 weeks showed a greater improvement compared with interventions ≤ 12 weeks ($p = 0.03$; Table 3). Nevertheless, these improvements did not surpass the MDC of 0.36 m/s [55], indicating a lack of clinical significance.

6-Minute walk test: Three studies [30, 42, 49] reported a marked increase in the 6-min walking distance of 52.95 m for interventions ≤ 12 weeks ($p < 0.01$; I2: 34%; Fig. 3C). No subgroup analysis was applicable (Table 3), and no substantial publication bias was found ($p = 0.13$). However, this gain did not reach the MDC threshold of 79 m [60].

Changes in the knee muscle strength following later-stage exercise

Five studies involving 218 TKA patients assessed thigh muscle strength using a handheld dynamometer. The measurements were reported in kilograms-force [52, 54] and newtons [43, 45, 53], necessitating a kilograms-force conversion.

Knee flexor: Four studies [45, 52–54] showed a marked increase in the knee flexor strength of 3.36 kg-force ($p < 0.01$; I2: 91%; Fig. 4A). No marked improvement was observed for interventions ≤ 12 weeks ($p = 0.18$) [52, 53].

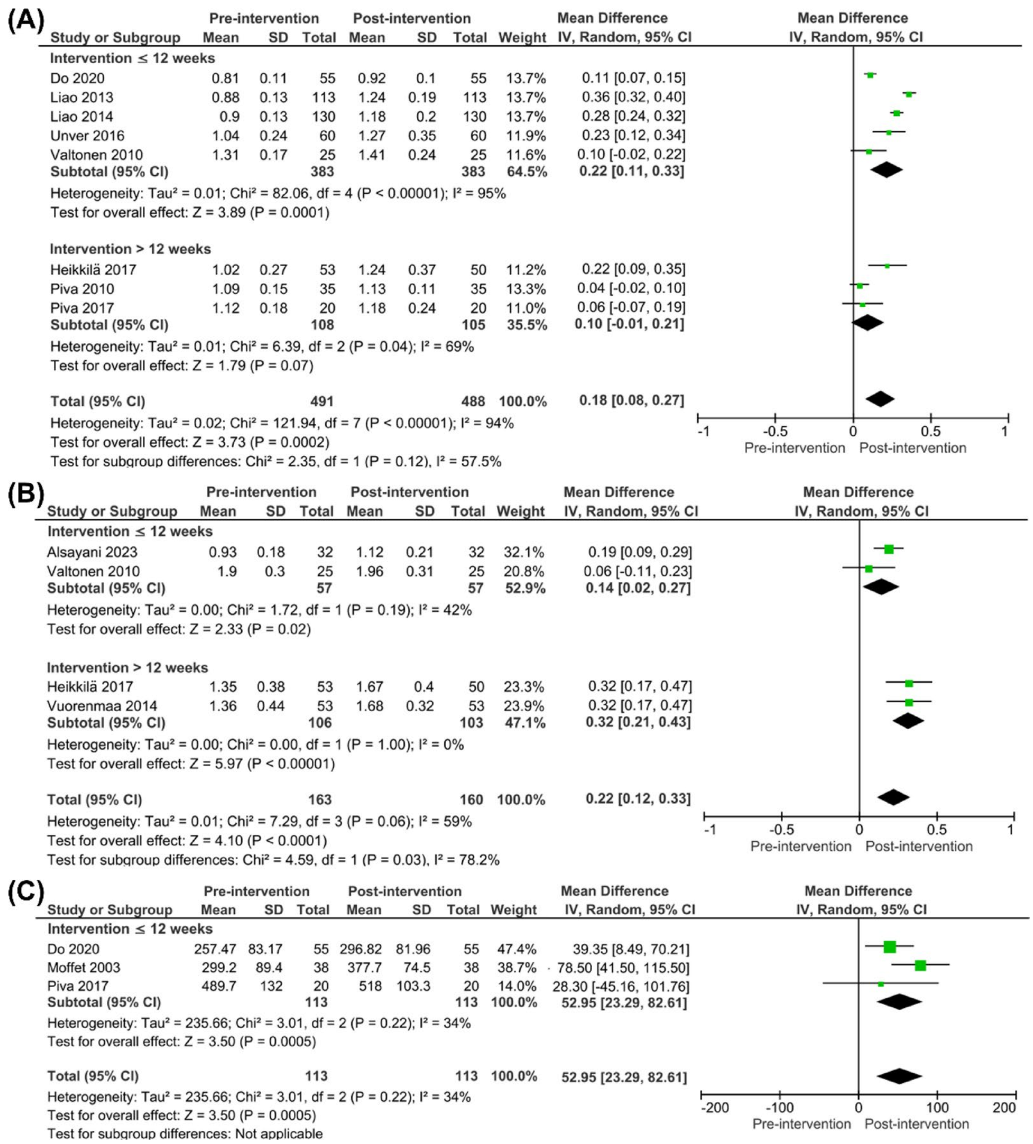

Fig. 3 Forest plots showing mean differences with 95% confidence intervals for changes in gait parameters following later-stage exercise interventions: **A** normal walking speed; **B** maximum walking speed; and **C** walking distance

Interventions > 12 weeks showed a marked increase of 4.67 kg-force [45, 54] ($p < 0.01$; I2: 0%). The subgroup differences were nonsignificant ($p = 0.05$; Table 3), and no publication bias was detected ($p = 0.54$).

Knee extensor: Five studies [43, 45, 52–54] indicated marked improvements in the knee extensor strength, depicting an overall increase of 7.03 kg-force ($p < 0.01$; I2: 95%; Fig. 4B). The increase for interventions ≤ 12 weeks was 1.57 kg-force [43, 52, 53] ($p < 0.01$; I2: 16%), whereas that for interventions > 12 weeks was 15.59 kg-force [45, 54] ($p < 0.01$; I2: 0%). The subgroup analysis indicated that interventions > 12 weeks showed greater improvement compared with interventions ≤ 12 weeks ($p < 0.01$; Table 3). No substantial publication bias was detected ($p = 0.46$). The increase in the knee muscle strength exceeded the MDC of 2.5 kg-force [61].

Changes in the knee range of motion following later-stage exercise

Five studies [42, 43, 51, 52, 54] involving 224 TKA patients assessed the knee range of motion following later-stage exercise interventions.

Knee flexion angle: Four studies [42, 43, 52, 54] reported an overall increase in the knee flexion angle of 7.90° ($p < 0.01$; I2: 75%; Fig. 4C). The increase for interventions ≤ 12 weeks was 5.42° [42, 43, 52] ($p < 0.01$; I2: 5%), whereas that for interventions > 12 weeks was 14.40° [54] ($p < 0.01$). The subgroup analysis indicated that interventions > 12 weeks showed greater improvement compared

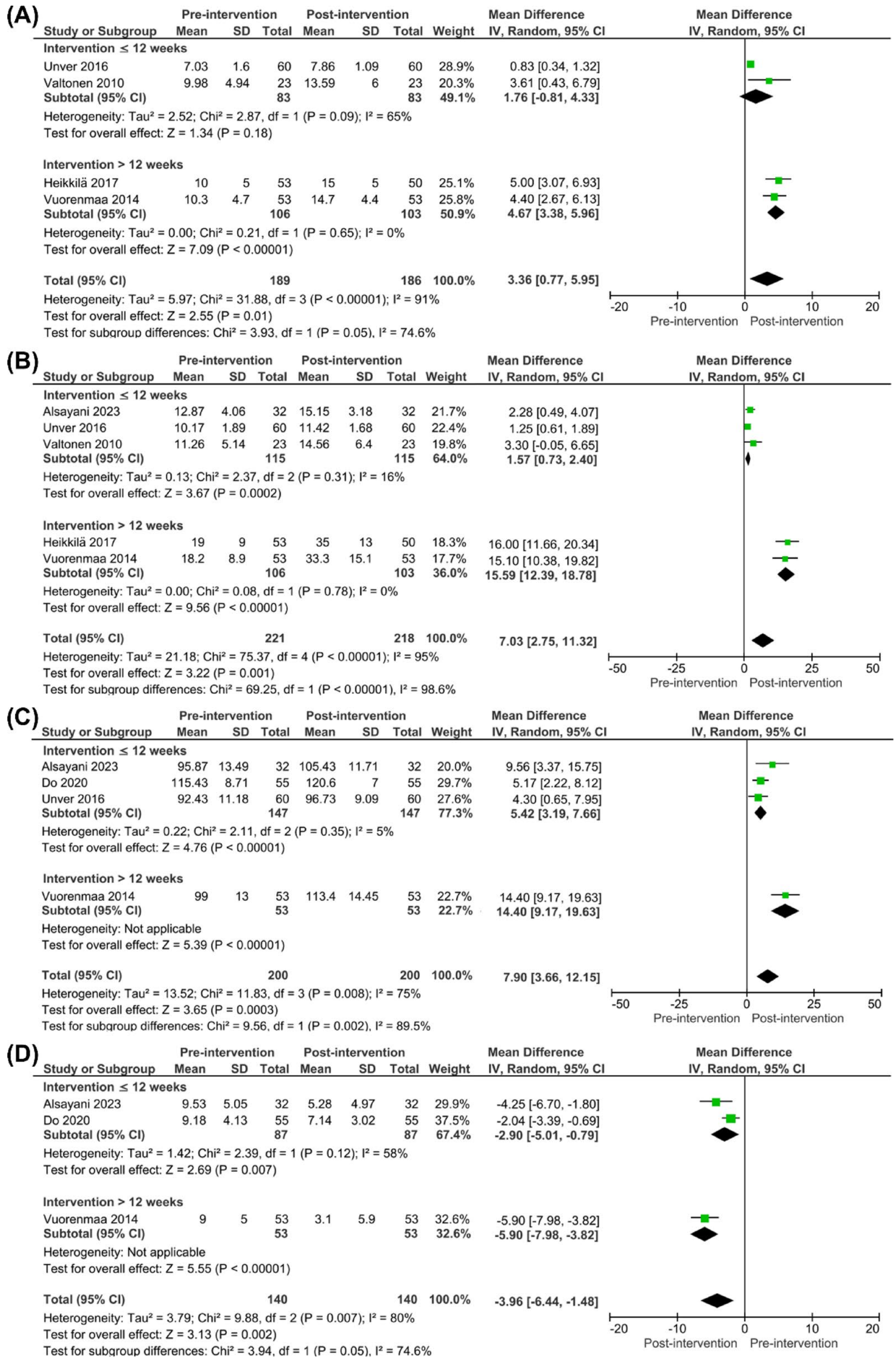

Fig. 4 Forest plots showing mean differences with 95% confidence intervals for changes in knee muscle strength and range of motion following later-stage exercise interventions: **A** knee flexor; **B** knee extensor; **C** knee flexion angle; and **D** knee extension angle

with interventions ≤ 12 weeks ($p < 0.01$; Table 3). No substantial publication bias was found ($p = 0.55$).

Knee extension angle: Three studies [42, 43, 54] reported a marked reduction in the knee extension angle of 3.96° ($p < 0.01$; I2: 80%; Fig. 4D). The reduction for interventions ≤ 12 weeks was 2.90° [42, 43] ($p < 0.01$; I2: 58%), whereas that for interventions > 12 weeks was 5.90° [54] ($p < 0.01$; 95%CI: – 7.98, – 3.82). The subgroup differences were nonsignificant ($p = 0.05$; Table 3), and no substantial publication bias was found ($p = 0.69$). The increase in the knee range of motion exceeded the MDC of 7.9° and 3.8° for flexion and extension, respectively [62]. The high heterogeneity of this outcome may be due to the fewer studies included.

Changes in the subjective outcome following later-stage exercise

Pain intensity: Six studies [43–45, 50, 52, 53] involving 536 TKA patients assessed the pain intensity using a visual analog scale. Four studies [43, 44, 50, 52] used a 10-point scale, whereas two [45, 53] used a 100-point scale converted to a 10-point scale. For interventions ≤ 12 weeks, four studies [43, 44, 52, 53] reported a marked reduction of 1.18 points ($p < 0.01$; I2: 87%). For interventions > 12 weeks, two studies [45, 50] showed a reduction of 0.72 points ($p < 0.01$). The overall analysis indicated a considerable decrease of 1.04 points [43–45, 50, 52, 53] ($p < 0.01$; I2: 83%; Fig. 5A). The subgroup differences were nonsignificant ($p = 0.31$; Table 3). No publication bias was detected ($p = 0.34$), but the reduction did not meet the MDC of 2.8 points [60]. The substantial heterogeneity of this outcome may be caused by the differing scales of the included studies.

Disability score: Twelve studies [28, 30, 42–44, 47–50, 52–54] with 1,072 TKA patients evaluated the disability scores using various tools, including the Western Ontario and McMaster Universities Osteoarthritis Index [28, 30, 42, 43, 47–50, 53, 54], the Oxford Knee Score [44], and the Hospital for Special Surgery Score [52].

The reduction for interventions ≤ 12 weeks was 17.18% [28, 42–44, 47–49, 52, 53] ($p < 0.01$; I2: 100%), whereas that for interventions > 12 weeks was 10.40% [30, 50, 54] ($p = 0.03$). The overall reduction was 15.59% [28, 30, 42–44, 47–50, 52–54] ($p < 0.01$; I2: 99%; Fig. 5B). The subgroup differences were nonsignificant ($p = 0.34$; Table 3). No publication bias was detected ($p = 0.44$), but the observed reduction did not reach the MDC of 19% [60]. The substantial heterogeneity of this outcome may be caused by the varying questionnaire use across the included studies.

Mental status: Three studies [43, 49, 54] involving 123 TKA patients assessed the mental status using the 36-Item Short Form Survey [49, 54] and the WHO Quality-of-Life Scale [43]. The data were reported on a 100-point scale. For interventions ≤ 12 weeks, two studies [43, 49] showed a marked increase of 5.19 points ($p < 0.01$; I2: 0%). For interventions > 12 weeks, one study [54] depicted an increase of 4.00 points ($p = 0.01$). Overall, the mental well-being showed an improvement of 4.57 points [43, 49, 54] ($p < 0.01$; I2: 0%; Fig. 5C). The subgroup differences were nonsignificant ($p = 0.61$; Table 3). No publication bias was detected ($p = 0.51$), but the improvement did not exceed the MDC of 15 points [63].

Certainty of evidence

The certainty of evidence was downgraded due to bias, inconsistency, or imprecision, ranging from very low to moderate (Table 4). The very low-certainty evidence supported outcomes, such as the timed up-and-go test and range of motion. The low-certainty evidence was observed for the chair stand test, single-leg stance, maximum walking speed, walking distance, muscle strength, disability score, and mental status. The moderate certainty evidence supported five-times sit-to-stand test, stair climbing, normal walking speed, and pain intensity.

Discussion

This review is the first to systematically evaluate the impact of later-stage exercise interventions on the knee outcome measures over time in patients who underwent TKA, performing a comparison between interventions implemented ≤ 12 weeks and those performed > 12 weeks. The evidence ranged from low to moderate risk of bias and very low to moderate certainty, indicating robust findings for some outcomes [36]. Most studies provided moderate levels of detail in their intervention descriptions, which may need greater detail to be sufficient for protocol replication in clinical practice [33].

The exercise interventions conducted for 12 weeks primarily resulted in functional performance outcomes, including sit-to-stand, timed up-and-go, and stair climbing, improvements that are likely attributed to neuromuscular adaptations and enhanced coordination [64], which predominantly affect the functional performance outcomes. Functional performance is often considered a key indicator of one's physical well-being [65]. Previous meta-analyses [20, 21] emphasized the importance of early rehabilitation for improving functional performance after TKA. The present study found that later-stage exercise interventions yielded smaller functional performance improvements likely due to the reduced potential for further gains during this recovery phase. In contrast, substantial gains in the knee strength and range of motion require a longer duration because they rely on tissue adaptation and recovery processes [16]. Therefore, our review highlights that interventions lasting ≤ 12 weeks are effective in enhancing functional

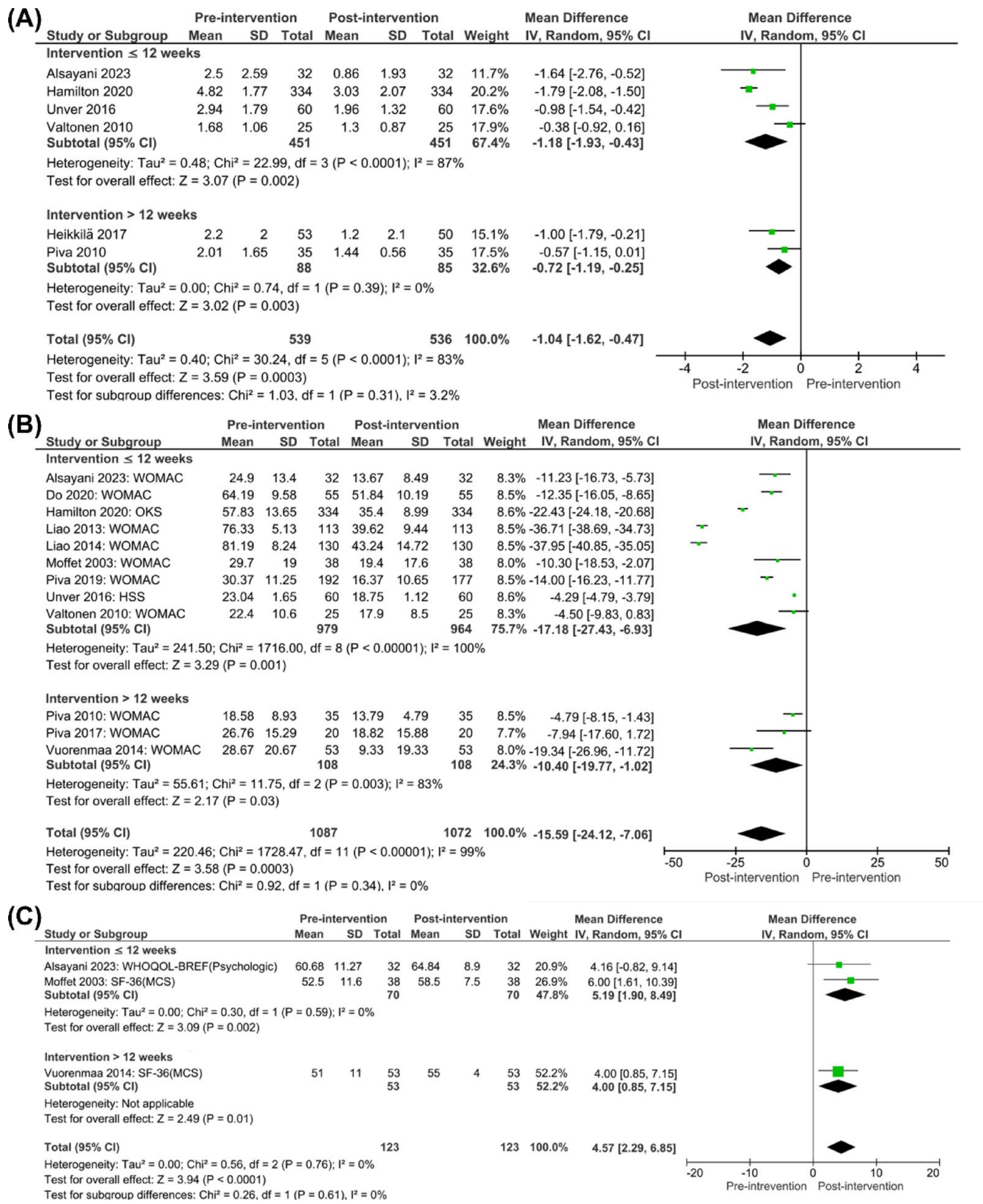

Fig. 5 Forest plots showing mean differences with 95% confidence intervals for changes in subjective outcome following later-stage exercise interventions: **A** pain intensity; **B** disability score; and **C** mental status. HSS, Hospital for Special Surgery; OKS, Oxford Knee Score; SF-36(MCS), 36-Item Short Form Survey (mental component summary); WHOQOL-BREF, World Health Organization Quality of Life Instrument; WOMAC, Western Ontario and McMaster Universities Osteoarthritis

performance, but those > 12 weeks are beneficial for improving strength and range of motion.

Most of the included studies combined various exercise types, with strengthening exercises being the primary focus for both durations. Studies with ≤ 12-week interventions more often included functional training as a secondary component, whereas those lasting > 12 weeks were more likely to incorporate stretching exercises, suggesting that strengthening should be the main focus in the later stages of post-TKA rehabilitation. Despite strengthening the quadriceps and the hamstrings in TKA patients, many still demonstrated lower muscle strength compared with that of healthy adults of the same age [14, 15, 65]. Research also indicated a reduction in the knee muscle power on the operated side compared to the non-operated side [27]. For prevention of muscular imbalances, our results strongly support the inclusion of strengthening exercises in TKA rehabilitation programs, emphasizing the need for long-term interventions lasting more than 12 weeks.

Post-TKA patients often experience limited knee joint flexibility on the operated side [27]. To address this issue, range of motion and stretching exercises are recommended for stretching the joint capsule and muscle fibers [66]. The studies included in this review focused on the knee and considered the hip and ankle joints, which are the proximal and distal joints, respectively. Many studies [67, 68] highlighted that changes in one joint can marked affect the flexibility of the adjacent joints. Hence, later-stage exercise programs should incorporate range of motion and stretching exercises targeting all the lower extremity joints. Our review also suggests that interventions lasting longer than 12 weeks are beneficial for improving knee flexibility.

Interventions lasting > 12 weeks may also show functional performance improvements. However, the wider confidence intervals and the fewer studies in this group introduce greater variability and uncertainty. Consequently, the effects on functional performance in longer-duration interventions are found to be less certain compared with those observed in interventions lasting ≤ 12 weeks. Note also that the ≤ 12-week studies more greatly emphasized on functional training, even though the percentage differences were not substantial, and the number of studies varied between the two duration groups. Hence, interventions lasting > 12 weeks appeared to show less marked improvement in functional performance compared with those lasting ≤ 12 weeks.

This review demonstrates that later-stage exercise interventions lead to subjective outcome improvements over time, including pain and disability reductions and mental well-being enhancements. Previous studies [69, 70] have suggested that exercise triggers the release of endorphins, which help alleviate pain and improve emotions, thereby leading to enhanced subjective well-being. Pain relief may also result from breaking scar adhesions and improving joint mobility [6, 70]. However, pain improvements resulting from later-stage exercise interventions do not appear to marked differ between the intervention durations (≤ 12 weeks vs > 12 weeks). The overall changes in the pain outcomes also seem less pronounced than those reported in previous review studies examining the effects of TKA surgery itself [6–8], suggesting that surgical intervention may address these issues more effectively compared with exercise during the later recovery stages.

The MDC for the following knee outcome measures must be considered: sit-to-stand, – 1.7 s [55] or one repetition [56]; timed up-and-go, – 1.1 s [57]; stair climbing, – 0.2 s [58]; single-leg stance, 19 s [59]; walking speed, 0.36 m/s [55]; walking distance, 79 m [60]; knee muscle strength, 2.5 kg-force [61]; knee flexion/extension angles, 7.9/ – 3.8° [62]; pain intensity, – 2.8 points [60]; disability score, – 19% [60]; and mental status, 15 points [63]. Although the improvements in the sit-to-stand performance, timed up-and-go, stair climbing, knee muscle strength, and knee extension angle exceeded the MDC values, later-stage exercise interventions did not meet the threshold for the other knee outcome measures. Healthcare professionals should interpret these findings in conjunction with the established reference values when designing rehabilitation programs.

Many of the included studies highlighted the inconsistent and nonstandardized reporting of key intervention details, such as how exercise is implemented, monitored, and modified. This lack of standardization hinders the ability to compare the results across studies and limits the clinical implications of the findings. To address this issue and enhance the quality and applicability of future research, studies must clearly document the exercise protocols in accordance with the TIDieR checklist [33]. Standardizing the reporting of exercise protocols will improve the comparability of studies and facilitate a more informed approach in clinical settings, thereby enabling clinicians to design more effective rehabilitation programs.

Based on the review findings, we recommend the adoption of a tailored approach to later-stage rehabilitation. For short-term interventions (≤ 12 weeks), rehabilitation efforts must prioritize strengthening exercises and functional training. This focus will help improve patients' functional performance. In contrast, long-term interventions (> 12 weeks) should greatly emphasize strengthening exercises in association with stretching techniques. This approach is essential for enhancing the muscle strength and joint flexibility. Clinicians should adjust rehabilitation strategies accordingly to ensure that they are aligned with both the expected improvements over time and the patient's specific needs.

This meta-analysis has some limitations. First, the population factors (e.g., primary vs. revision TKA, unilateral vs. bilateral procedures, surgical techniques, and time since surgery) were not considered because some studies reported incomplete data. The studies included in this review had a wide range of time since surgery, that is, from 2 to 48 months, which could contribute to the result heterogeneity. Second, the conclusions may not apply to patients using combination therapies. Third, a considerable number of the included studies were conducted by the same research group, consequently raising concerns about a potential publication bias, especially regarding the timed up-and-go outcomes. Additionally, only studies published in English were considered, potentially leading to language bias. These factors may limit the robustness of the findings. Lastly, the absence of consistent comparator groups limits the ability to draw definitive causal conclusions because defining true negative or diverse positive controls is challenging. This limitation also complicates the ability to account for factors such as self-recovery over time. To strengthen causal inferences, future studies must include specific comparator groups to better isolate the intervention effects.

In conclusion, this review emphasizes the importance of incorporating later-stage exercises into rehabilitation following the early-stage interventions used in patients with TKA. Strengthening exercises must be a key component of this stage, regardless of whether the exercise intervention lasts ≤ 12 or > 12 weeks. However, each duration offers distinct benefits for specific outcomes. Interventions lasting ≤ 12 weeks will improve functional performance, whereas those lasting > 12 weeks will lead to more notable gains in the muscle strength and joint flexibility. Clinicians can tailor post-TKA rehabilitation programs to focus on these specific outcomes based on the exercise intervention duration. Although the certainty of the evidence ranges from low to moderate, the findings suggest the potential advantages of later-stage exercise in post-TKA rehabilitation. Furthermore, comprehensive reports on intervention protocols must be aligned with the TIDieR checklist to ensure their effective replication in clinical practice as most studies provide only moderate details.

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

Supplementary Material 4

Supplementary Material 5

Supplementary Material 6

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Authors contributions
Conceptualization: PK, RV, JR, and KS; writing—original draft: PK; writing—review and editing: RV, JR, and KS; data curation: PK and KS; formal analysis: PK; methodology: PK and RV; supervision: RV, JR, and KS; resources: WK, NK, and SS; and validation: WK, NK, and SS.

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Declarations

Ethics approval and consent to participate
This study is a systematic review and meta-analysis; therefore, ethical approval is not required.

Consent for publication
Not applicable.

Competing Interests
The authors declare no competing interests.

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