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Title

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.

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.

Trial registration: PROSPERO systematic review protocol (ID: CRD42023438253)

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

1 knowledge gap remains in terms of the exercise interventions implemented after early-
2 stage rehabilitation.

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

16 In clinical practice, implementing exercise programs is often challenging because of
17 the inadequate reporting of interventions. Hoffman et al. (2014) emphasized the
18 importance of specifying key features such as duration, intensity, delivery mode, and
19 monitoring procedures [33]. For clarity enhancement, the Template for Intervention
20 Description and Replication (TIDieR) checklist encourages authors to include the key
21 intervention details for replication and clinical application [34]. Hence, this study aims to
22 systematically evaluate the changes in the knee outcome measures following later-stage
23 exercise interventions, comparing those implemented within ≤ 12 weeks to those
24 implemented after > 12 weeks. Additionally, the certainty of the evidence and the
25 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].

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 I^2 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 $66 \pm 5\%$, 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] ($p < 0.01$; I^2 : 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] ($p < 0.01$, I^2 : 46%; **Fig. 2A**). The test for the subgroup differences was nonsignificant ($p = 0.70$; **Table 3**), and no substantial publication bias was detected ($p = 0.32$). 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 ($p < 0.01$; I^2 : 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 ($p < 0.01$; I^2 : 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] ($p < 0.01$; I^2 : 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, three studies [43, 47, 48] showed marked duration reductions of 3.35 s ($p < 0.01$; I^2 : 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] ($p < 0.01$; I^2 : 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 ($p < 0.01$; I^2 : 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] ($p < 0.01$; I^2 : 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 ($p < 0.01$; I^2 : 94%; **Fig. 3A**). Interventions ≤ 12 weeks resulted in a marked increase of 0.22 m/s [42, 47, 48, 52, 53] ($p < 0.01$; I^2 : 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] ($p < 0.01$; I^2 : 59%; **Fig. 3B**). No publication bias was detected ($p = 0.89$). For interventions ≤ 12 weeks, a significant increase of 0.14 m/s was observed [43, 53] ($p < 0.01$; I^2 : 42%). For interventions >12 weeks, the increase was 0.32 m/s [45, 54] ($p < 0.01$; I^2 : 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-minute walking distance of 52.95 m for interventions ≤ 12 weeks ($p < 0.01$; I^2 : 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 kilograms-force ($p < 0.01$; I^2 : 91%; **Fig. 4A**). No marked improvement was observed for interventions ≤ 12 weeks ($p = 0.18$) [52, 53]. Interventions > 12 weeks showed a marked increase of 4.67 kilograms-force [45, 54] ($p < 0.01$; I^2 : 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 kilograms-force ($p < 0.01$; I^2 : 95%; **Fig. 4B**). The increase for interventions ≤ 12 weeks was 1.57 kilograms-force [43, 52, 53] ($p < 0.01$; I^2 : 16%), whereas that for interventions > 12 weeks was 15.59 kilograms-force [45, 54] ($p < 0.01$; I^2 : 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 kilograms-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° ($p < 0.01$; I^2 : 75%; **Fig. 4C**). The increase for interventions ≤ 12 weeks was 5.42° [42, 43, 52] ($p < 0.01$; I^2 : 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 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° ($p < 0.01$; I^2 : 80%; **Fig. 4D**). The reduction for interventions

1 ≤ 12 weeks was 2.90° [42, 43] ($p < 0.01$; I^2 : 58%), whereas that for interventions > 12
2 weeks was 5.90° [54] ($p < 0.01$; 95%CI: $-7.98, -3.82$). The subgroup differences were
3 nonsignificant ($p = 0.05$; **Table 3**), and no substantial publication bias was found ($p =$
4 0.69). The increase in the knee range of motion exceeded the MDC of 7.9° and 3.8° for
5 flexion and extension, respectively [62]. The high heterogeneity of this outcome may be
6 due to the fewer studies included.

7 **Changes in the subjective outcome following later-stage exercise**

8 *Pain intensity*: Six studies [43-45, 50, 52, 53] involving 536 TKA patients assessed the
9 pain intensity using a visual analog scale. Four studies [43, 44, 50, 52] used a 10-point
10 scale, whereas two [45, 53] used a 100-point scale converted to a 10-point scale. For
11 interventions ≤ 12 weeks, four studies [43, 44, 52, 53] reported a marked reduction of 1.18
12 points ($p < 0.01$; I^2 : 87%). For interventions > 12 weeks, two studies [45, 50] showed a
13 reduction of 0.72 points ($p < 0.01$). The overall analysis indicated a considerable decrease
14 of 1.04 points [43-45, 50, 52, 53] ($p < 0.01$; I^2 : 83%; **Fig. 5A**). The subgroup differences
15 were nonsignificant ($p = 0.31$; **Table 3**). No publication bias was detected ($p = 0.34$), but
16 the reduction did not meet the MDC of 2.8 points [60]. The substantial heterogeneity of
17 this outcome may be caused by the differing scales of the included studies.

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

22 The reduction for interventions ≤ 12 weeks was 17.18% [28, 42-44, 47-49, 52, 53] (p
23 < 0.01 ; I^2 : 100%), whereas that for interventions > 12 weeks was 10.40% [30, 50, 54] (p
24 $= 0.03$). The overall reduction was 15.59% [28, 30, 42-44, 47-50, 52-54] ($p < 0.01$; I^2 :
25 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 ($p < 0.01$; $I^2: 0\%$). 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] ($p < 0.01$; $I^2: 0\%$; **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 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 markedly 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 kilograms-force [61]; knee flexion/extension angles, $7.9/-3.8^\circ$ [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.

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.

Availability of data and materials

The online version contains supplementary material available at ...

Competing interests

The authors declare that they have no competing interests.

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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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Trial details

The protocol for this systematic review and meta-analysis was prospectively registered with PROSPERO (CRD42023438253).

References

1. Cram P, Lu X, Kates SL, Singh JA, Li Y, Wolf BR. Total knee arthroplasty volume, utilization, and outcomes among medicare beneficiaries, 1991-2010. *Jama*. 2012;308(12):1227-36.<https://doi.org/10.1001/2012.jama.11153>.
2. Culliford D, Maskell J, Judge A, Cooper C, Prieto-Alhambra D, Arden NK. Future projections of total hip and knee arthroplasty in the UK: results from the UK Clinical Practice Research Datalink. *Osteoarthritis Cartilage*. 2015;23(4):594-600.<https://doi.org/10.1016/j.joca.2014.12.022>.
3. Inacio MCS, Paxton EW, Graves SE, Namba RS, Nemes S. Projected increase in total knee arthroplasty in the United States - an alternative projection model. *Osteoarthritis Cartilage*. 2017;25(11):1797-803.<https://doi.org/10.1016/j.joca.2017.07.022>.
4. Maradit Kremers H, Larson DR, Crowson CS, Kremers WK, Washington RE, Steiner CA, et al. Prevalence of total hip and knee replacement in the United States. *J Bone Joint Surg Am*. 2015;97(17):1386-97.<https://doi.org/10.2106/jbjs.N.01141>.
5. Gao J, Xing D, Dong S, Lin J. The primary total knee arthroplasty: a global analysis. *J Orthop Surg Res*. 2020;15(1):190.<https://doi.org/10.1186/s13018-020-01707-5>.
6. Terkawi AS, Mavridis D, Sessler DI, Nunemaker MS, Doais KS, Terkawi RS, et al. Pain management modalities after total knee arthroplasty: a network meta-analysis of 170 randomized controlled trials. *Anesthesiology*. 2017;126(5):923-37.<https://doi.org/10.1097/aln.0000000000001607>.

7. Shan L, Shan B, Suzuki A, Nough F, Saxena A. Intermediate and long-term quality of life after total knee replacement: a systematic review and meta-analysis. *J Bone Joint Surg Am*. 2015;97(2):156-68.<https://doi.org/10.2106/jbjs.M.00372>.
8. Aujla RS, Esler CN. Total knee arthroplasty for osteoarthritis in patients less than fifty-five years of age: a systematic review. *J Arthroplasty*. 2017;32(8):2598-603.e1.<https://doi.org/10.1016/j.arth.2017.02.069>.
9. Accatino G, Monzio Compagnoni A, Grassi FA, Castelli A, Pasta G, Benazzo F, et al. Bilateral total knee arthroplasty (TKA) in a one-stage procedure versus two-stage procedure: a retrospective study. *Healthcare (Basel)*. 2024;12(18).<https://doi.org/10.3390/healthcare12181902>.
10. Li X, Lai J, Yang X, Xu H, Xiang S. Intra-articular injection of vancomycin after arthrotomy closure following gentamicin-impregnated bone cementation in primary total knee arthroplasty provides a high intra-articular concentration while avoiding systemic toxicity: a prospective study. *J Orthop Surg Res*. 2024;19(1):856.<https://doi.org/10.1186/s13018-024-05357-9>.
11. Yang J, Li X, Liu P, Liu X, Li L, Zhang M. The impact of patellofemoral joint diseases on functional outcomes and prosthesis survival in patients undergoing unicompartmental knee arthroplasty: a systematic review and meta-analysis. *J Orthop Surg Res*. 2024;19(1):840.<https://doi.org/10.1186/s13018-024-05273-y>.
12. Zhao C, Liao Q, Yang D, Yang M, Xu P. Advances in perioperative pain management for total knee arthroplasty: a review of multimodal analgesic approaches. *J Orthop Surg Res*. 2024;19(1):843.<https://doi.org/10.1186/s13018-024-05324-4>.
13. Liu Y, Xing Z, Wu B, Chen N, Wu T, Cai Z, et al. Association of MRI-based knee osteoarthritis structural phenotypes with short-term structural progression and

subsequent total knee replacement. J Orthop Surg Res. 2024;19(1):699.<https://doi.org/10.1186/s13018-024-05194-w>.

14. Ro DH, Kang T, Han DH, Lee DY, Han HS, Lee MC. Quantitative evaluation of gait features after total knee arthroplasty: Comparison with age and sex-matched controls. Gait Posture. 2020;75:78-84.<https://doi.org/10.1016/j.gaitpost.2019.09.026>.

15. Glass NA, Segal NA, Callaghan JJ, Clark CR, Noiseux NO, Gao Y, et al. Comparison of the extent to which total hip and total knee arthroplasty restore patient-reported physical function. Osteoarthritis Cartilage. 2016;24(11):1875-82.<https://doi.org/10.1016/j.joca.2016.06.010>.

16. Flick TR, Wang CX, Patel AH, Hodo TW, Sherman WF, Sanchez FL. Arthrofibrosis after total knee arthroplasty: patients with keloids at risk. J Orthop Traumatol. 2021;22(1):1.<https://doi.org/10.1186/s10195-020-00563-7>.

17. Xing P, Qu J, Feng S, Guo J, Huang T. Comparison of the efficacy of robot-assisted total knee arthroplasty in patients with knee osteoarthritis with varying severity deformity. J Orthop Surg Res. 2024;19(1):872.<https://doi.org/10.1186/s13018-024-05372-w>.

18. Bade MJ, Kohrt WM, Stevens-Lapsley JE. Outcomes before and after total knee arthroplasty compared to healthy adults. J Orthop Sports Phys Ther. 2010;40(9):559-67.<https://doi.org/10.2519/jospt.2010.3317>.

19. Alrawashdeh W, Eschweiler J, Migliorini F, El Mansy Y, Tingart M, Rath B. Effectiveness of total knee arthroplasty rehabilitation programmes: A systematic review and meta-analysis. J Rehabil Med. 2021;53(6):jrm00200.<https://doi.org/10.2340/16501977-2827>.

20. Artz N, Elvers KT, Lowe CM, Sackley C, Jepson P, Beswick AD. Effectiveness of physiotherapy exercise following total knee replacement: systematic review and

meta-analysis. BMC Musculoskelet Disord. 2015;16:15.<https://doi.org/10.1186/s12891-015-0469-6>.

21. Pozzi F, Snyder-Mackler L, Zeni J. Physical exercise after knee arthroplasty: a systematic review of controlled trials. Eur J Phys Rehabil Med. 2013;49(6):877-92

22. Vervullens S, Meert L, Baert I, Smeets RJEM, Verdonk P, Rahusen F, et al.

Prehabilitation before total knee arthroplasty: A systematic review on the use and efficacy of stratified care. Ann Phys Rehabil Med.

2023;66(4):101705.<https://doi.org/10.1016/j.rehab.2022.101705>.

23. Minns Lowe CJ, Barker KL, Dewey M, Sackley CM. Effectiveness of

physiotherapy exercise after knee arthroplasty for osteoarthritis: systematic review and meta-analysis of randomised controlled trials. Bmj.

2007;335(7624):812.<https://doi.org/10.1136/bmj.39311.460093.BE>.

24. Paravlic AH, Maffulli N, Kovač S, Pisot R. Home-based motor imagery

intervention improves functional performance following total knee arthroplasty in the short term: a randomized controlled trial. J Orthop Surg Res.

2020;15(1):451.<https://doi.org/10.1186/s13018-020-01964-4>.

25. Morelli I, Maffulli N, Brambilla L, Agnoletto M, Peretti GM, Mangiavini L.

Quadriceps muscle group function and after total knee arthroplasty-asystematic

narrative update. Br Med Bull. 2021;137(1):51-69.<https://doi.org/10.1093/bmb/ldaa041>.

26. LaStayo PC, Meier W, Marcus RL, Mizner R, Dibble L, Peters C. Reversing

muscle and mobility deficits 1 to 4 years after TKA: a pilot study. Clin Orthop Relat Res. 2009;467(6):1493-500.<https://doi.org/10.1007/s11999-009-0801-2>.

27. Jette DU, Hunter SJ, Burkett L, Langham B, Logerstedt DS, Piuze NS, et al.

Physical therapist management of total knee arthroplasty. Phys Ther. 2020;100(9):1603-

31.<https://doi.org/10.1093/ptj/pzaa099>.

28. Piva SR, Schneider MJ, Moore CG, Catelani MB, Gil AB, Klatt BA, et al. Effectiveness of later-stage exercise programs vs usual medical care on physical function and activity after total knee replacement: a randomized clinical trial. *JAMA Netw Open*. 2019;2(2):e190018.<https://doi.org/10.1001/jamanetworkopen.2019.0018>.
29. Fransen M, Nairn L, Bridgett L, Crosbie J, March L, Parker D, et al. Post-acute rehabilitation after total knee replacement: a multicenter randomized clinical trial comparing long-term outcomes. *Arthritis Care Res (Hoboken)*. 2017;69(2):192-200.<https://doi.org/10.1002/acr.23117>.
30. Piva SR, Almeida GJ, Gil AB, DiGioia AM, Helsel DL, Sowa GA. Effect of comprehensive behavioral and exercise intervention on physical function and activity participation after total knee replacement: a pilot randomized study. *Arthritis Care Res (Hoboken)*. 2017;69(12):1855-62.<https://doi.org/10.1002/acr.23227>.
31. Groot L, Latijnhouwers D, Reijman M, Verdegaal SHM, Vliet Vlieland TPM, Gademan MGJ. Recovery and the use of postoperative physical therapy after total hip or knee replacement. *BMC Musculoskelet Disord*. 2022;23(1):666.<https://doi.org/10.1186/s12891-022-05429-z>.
32. Geneen LJ, Moore RA, Clarke C, Martin D, Colvin LA, Smith BH. Physical activity and exercise for chronic pain in adults: an overview of Cochrane Reviews. *Cochrane Database Syst Rev*. 2017;4(4):Cd011279.<https://doi.org/10.1002/14651858.CD011279.pub3>.
33. Hoffmann TC, Glasziou PP, Boutron I, Milne R, Perera R, Moher D, et al. Better reporting of interventions: template for intervention description and replication (TIDieR) checklist and guide. *Bmj*. 2014;348:g1687.<https://doi.org/10.1136/bmj.g1687>.

34. Jones E, Lees N, Martin G, Dixon-Woods M. Describing methods and interventions: a protocol for the systematic analysis of the perioperative quality improvement literature. *Syst Rev*. 2014;3:98.<https://doi.org/10.1186/2046-4053-3-98>.
35. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *Bmj*. 2021;372:n71.<https://doi.org/10.1136/bmj.n71>.
36. de Morton NA. The PEDro scale is a valid measure of the methodological quality of clinical trials: a demographic study. *Aust J Physiother*. 2009;55(2):129-33.[https://doi.org/10.1016/s0004-9514\(09\)70043-1](https://doi.org/10.1016/s0004-9514(09)70043-1).
37. Kantha P, Lin JJ, Hsu WL. The effects of interactive virtual reality in patients with chronic musculoskeletal disorders: a systematic review and meta-analysis. *Games Health J*. 2023;12(1):1-12.<https://doi.org/10.1089/g4h.2022.0088>.
38. Mack DE, Wilson PM, Santos E, Brooks K. Standards of reporting: the use of CONSORT PRO and CERT in individuals living with osteoporosis. *Osteoporos Int*. 2018;29(2):305-13.<https://doi.org/10.1007/s00198-017-4249-z>.
39. Kattackal TR, Cavallo S, Brosseau L, Sivakumar A, Del Bel MJ, Dorion M, et al. Assessing the reporting quality of physical activity programs in randomized controlled trials for the management of juvenile idiopathic arthritis using three standardized assessment tools. *Pediatr Rheumatol Online J*. 2020;18(1):41.<https://doi.org/10.1186/s12969-020-00434-9>.
40. Guyatt GH, Oxman AD, Vist GE, Kunz R, Falck-Ytter Y, Alonso-Coello P, et al. GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. *Bmj*. 2008;336(7650):924-6.<https://doi.org/10.1136/bmj.39489.470347.AD>.

41. Higgins JPT, Green S (editors). Cochrane Handbook for Systematic Reviews of Interventions Version 5.1.0 [updated March 2011]. The Cochrane Collaboration, 2011. Available from www.handbook.cochrane.org.
42. Do K, Yim J. Effects of muscle strengthening around the hip on pain, physical function, and gait in elderly patients with total knee arthroplasty: a randomized controlled trial. Healthcare (Basel). 2020;8(4).<https://doi.org/10.3390/healthcare8040489>.
43. Alsayani KYA, Baş Aslan U, Bayrak G, Şavkın R, Büker N, Güngör HR. Comparison of the effectiveness of late-phase clinic-based and home-based progressive resistance training in female patients with total knee arthroplasty. Physiother Theory Pract. 2023;1-12.<https://doi.org/10.1080/09593985.2023.2205925>.
44. Hamilton DF, Beard DJ, Barker KL, Macfarlane GJ, Tuck CE, Stoddart A, et al. Targeting rehabilitation to improve outcomes after total knee arthroplasty in patients at risk of poor outcomes: randomised controlled trial. Bmj. 2020;371:m3576.<https://doi.org/10.1136/bmj.m3576>.
45. Heikkilä A, Sevander-Kreus N, Häkkinen A, Vuorenmaa M, Salo P, Konsta P, et al. Effect of total knee replacement surgery and postoperative 12 month home exercise program on gait parameters. Gait Posture. 2017;53:92-7.<https://doi.org/10.1016/j.gaitpost.2017.01.004>.
46. Hsu WH, Hsu WB, Shen WJ, Lin ZR, Chang SH, Hsu RW. Twenty-four-week hospital-based progressive resistance training on functional recovery in female patients post total knee arthroplasty. Knee. 2019;26(3):729-36.<https://doi.org/10.1016/j.knee.2019.02.008>.
47. Liao CD, Lin LF, Huang YC, Huang SW, Chou LC, Liou TH. Functional outcomes of outpatient balance training following total knee replacement in patients

- with knee osteoarthritis: a randomized controlled trial. Clin Rehabil. 2014;29(9):855-67.<https://doi.org/10.1177/0269215514564086>.
48. Liao CD, Liou TH, Huang YY, Huang YC. Effects of balance training on functional outcome after total knee replacement in patients with knee osteoarthritis: a randomized controlled trial. Clin Rehabil. 2013;27(8):697-709.<https://doi.org/10.1177/0269215513476722>.
49. Moffet H, Collet JP, Shapiro SH, Paradis G, Marquis F, Roy L. Effectiveness of intensive rehabilitation on functional ability and quality of life after first total knee arthroplasty: A single-blind randomized controlled trial. Arch Phys Med Rehabil. 2003;85(4):546-56.<https://doi.org/10.1016/j.apmr.2003.08.080>.
50. Piva SR, Gil AB, Almeida GJ, DiGioia AM, 3rd, Levison TJ, Fitzgerald GK. A balance exercise program appears to improve function for patients with total knee arthroplasty: a randomized clinical trial. Phys Ther. 2010;90(6):880-94.<https://doi.org/10.2522/ptj.20090150>.
51. Smith WA, Zucker-Levin A, Mihalko WM, Williams M, Loftin M, Gurney JG. A randomized study of exercise and fitness trackers in obese patients after total knee arthroplasty. Orthop Clin North Am. 2019;50(1):35-45.<https://doi.org/10.1016/j.ocl.2018.08.002>.
52. Unver B, Bakirhan S, Karatosun V. Does a weight-training exercise programme given to patients four or more years after total knee arthroplasty improve mobility: A randomized controlled trial. Arch Gerontol Geriatr. 2016;64:45-50.<https://doi.org/10.1016/j.archger.2016.01.003>.
53. Valtonen A, Pöyhönen T, Sipilä S, Heinonen A. Effects of aquatic resistance training on mobility limitation and lower-limb impairments after knee replacement. Arch Phys Med Rehabil. 2010;91(6):833-9.<https://doi.org/10.1016/j.apmr.2010.03.002>.

- 1 54. Vuorenmaa M, Ylinen J, Piitulainen K, Salo P, Kautiainen H, Pesola M, et al.
2 Efficacy of a 12-month, monitored home exercise programme compared with normal
3 care commencing 2 months after total knee arthroplasty: a randomized controlled trial. J
4 Rehabil Med. 2014;46(2):166-72.<https://doi.org/10.2340/16501977-1242>.
- 5 55. Amano T, Suzuki N. Minimal detectable change for motor function tests in
6 patients with knee osteoarthritis. Prog Rehabil Med.
7 2018;3:20180022.<https://doi.org/10.2490/prm.20180022>.
- 8 56. McAllister LS, Palombaro KM. Modified 30-second sit-to-stand test: reliability
9 and validity in older adults unable to complete traditional sit-to-stand testing. J Geriatr
10 Phys Ther. 2020;43(3):153-8.<https://doi.org/10.1519/jpt.0000000000000227>.
- 11 57. Alghadir A, Anwer S, Brismée JM. The reliability and minimal detectable
12 change of Timed Up and Go test in individuals with grade 1-3 knee osteoarthritis. BMC
13 Musculoskelet Disord. 2015;16:174.<https://doi.org/10.1186/s12891-015-0637-8>.
- 14 58. Iijima H, Shimoura K, Eguchi R, Aoyama T, Takahashi M. Concurrent validity
15 and measurement error of stair climb test in people with pre-radiographic to mild knee
16 osteoarthritis. Gait Posture. 2019;68:335-
17 9.<https://doi.org/10.1016/j.gaitpost.2018.12.014>.
- 18 59. Sarac DC, Unver B, Karatosun V. Validity and reliability of performance tests as
19 balance measures in patients with total knee arthroplasty. Knee Surg Relat Res.
20 2022;34(1):11.<https://doi.org/10.1186/s43019-022-00136-4>.
- 21 60. Naylor JM, Hayen A, Davidson E, Hackett D, Harris IA, Kamalasena G, et al.
22 Minimal detectable change for mobility and patient-reported tools in people with
23 osteoarthritis awaiting arthroplasty. BMC Musculoskelet Disord.
24 2014;15:235.<https://doi.org/10.1186/1471-2474-15-235>.

61. Kean CO, Birmingham TB, Garland SJ, Bryant DM, Giffin JR. Minimal detectable change in quadriceps strength and voluntary muscle activation in patients with knee osteoarthritis. Arch Phys Med Rehabil. 2010;91(9):1447-51.<https://doi.org/10.1016/j.apmr.2010.06.002>.
62. Mehta SP, Barker K, Bowman B, Galloway H, Oliashirazi N, Oliashirazi A. Reliability, concurrent validity, and minimal detectable change for iPhone goniometer app in assessing knee range of motion. J Knee Surg. 2017;30(6):577-84.<https://doi.org/10.1055/s-0036-1593877>.
63. Clement ND, Weir D, Holland J, Gerrand C, Deehan DJ. Meaningful changes in the Short Form 12 physical and mental summary scores after total knee arthroplasty. Knee. 2019;26(4):861-8.<https://doi.org/10.1016/j.knee.2019.04.018>.
64. Mau-Moeller A, Behrens M, Finze S, Bruhn S, Bader R, Mittelmeier W. The effect of continuous passive motion and sling exercise training on clinical and functional outcomes following total knee arthroplasty: a randomized active-controlled clinical study. Health Qual Life Outcomes. 2014;12:68.<https://doi.org/10.1186/1477-7525-12-68>.
65. Zeni JA, Jr., Snyder-Mackler L. Clinical outcomes after simultaneous bilateral total knee arthroplasty: comparison to unilateral total knee arthroplasty and healthy controls. J Arthroplasty. 2010;25(4):541-6.<https://doi.org/10.1016/j.arth.2009.02.016>.
66. Rodríguez-Merchán EC. The stiff total knee arthroplasty: causes, treatment modalities and results. EFORT Open Rev. 2019;4(10):602-10.<https://doi.org/10.1302/2058-5241.4.180105>.
67. Hiranaka T, Suda Y, Saitoh A, Tanaka A, Arimoto A, Koide M, et al. Current concept of kinematic alignment total knee arthroplasty and its derivatives. Bone Jt Open. 2022;3(5):390-7.<https://doi.org/10.1302/2633-1462.35.Bjo-2022-0021.R2>.

- 1 68. Chang AH, Chmiel JS, Almagor O, Hayes KW, Guermazi A, Prasad PV, et al.
2 Hip muscle strength and protection against structural worsening and poor function and
3 disability outcomes in knee osteoarthritis. *Osteoarthritis Cartilage*. 2019;27(6):885-
4 94.<https://doi.org/10.1016/j.joca.2019.02.795>.
- 5 69. Basso JC, Suzuki WA. The effects of acute exercise on mood, cognition,
6 neurophysiology, and neurochemical pathways: a review. *Brain Plast*. 2017;2(2):127-
7 52.<https://doi.org/10.3233/bpl-160040>.
- 8 70. Vaegter HB, Jones MD. Exercise-induced hypoalgesia after acute and regular
9 exercise: experimental and clinical manifestations and possible mechanisms in
10 individuals with and without pain. *Pain Rep*.
11 2020;5(5):e823.<https://doi.org/10.1097/pr9.0000000000000823>.

Figure captions

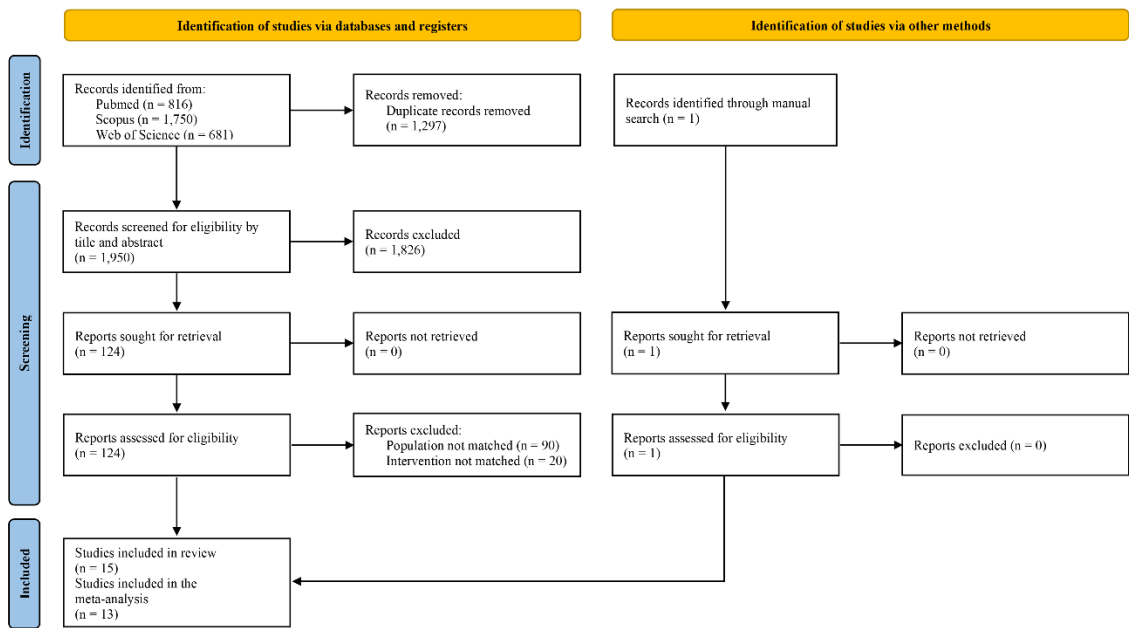


Fig. 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)

flow diagram summarizing the study screening and selection for review

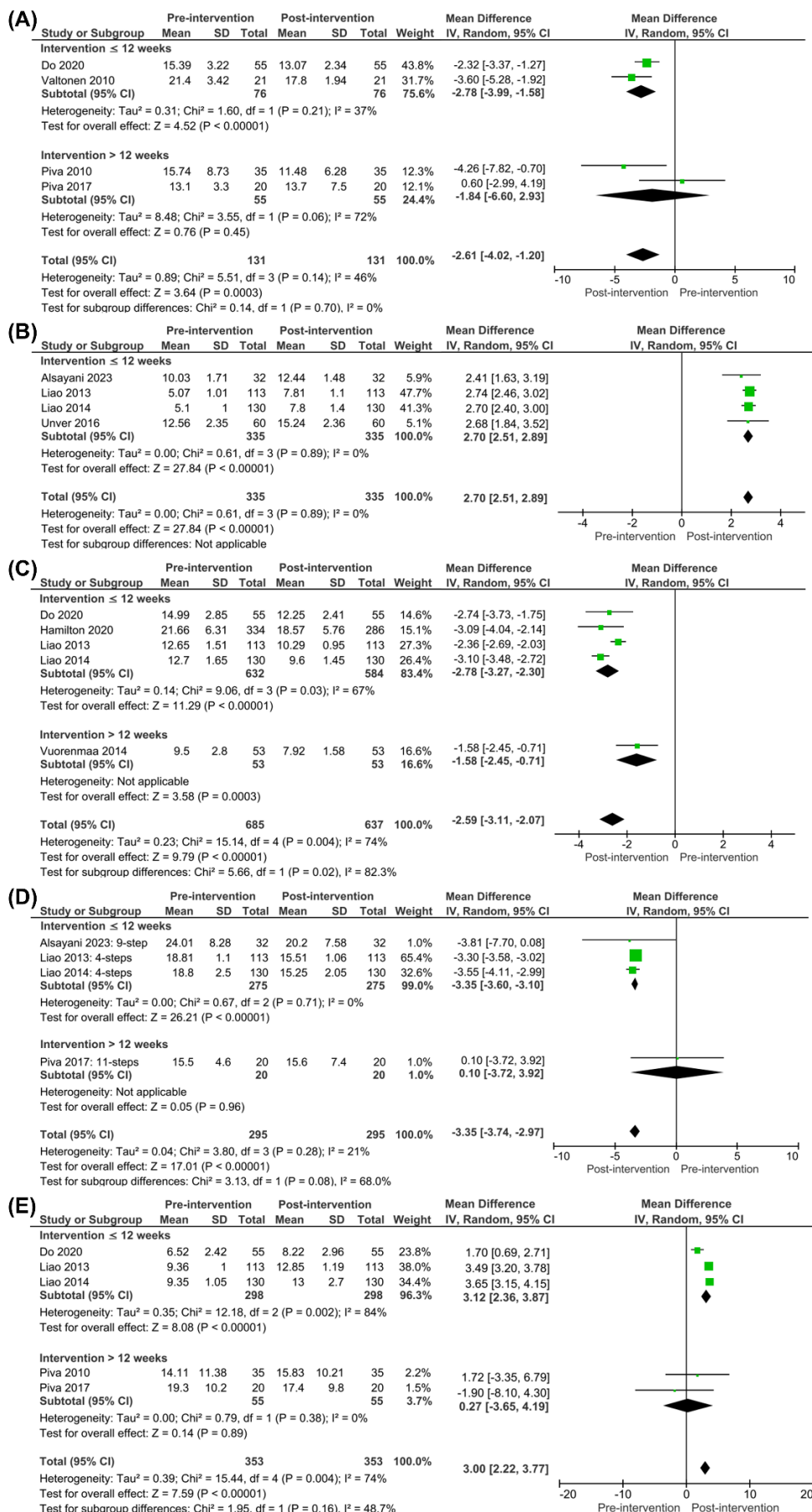


Fig. 2 Forest plots showing mean differences with 95% confidence intervals for changes in functional performance following later-stage exercise interventions: **(A)** five-times sit-to-stand test; **(B)** chair stand test; **(C)** timed up-and-go test; **(D)** stair climbing test; and **(E)** single-leg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

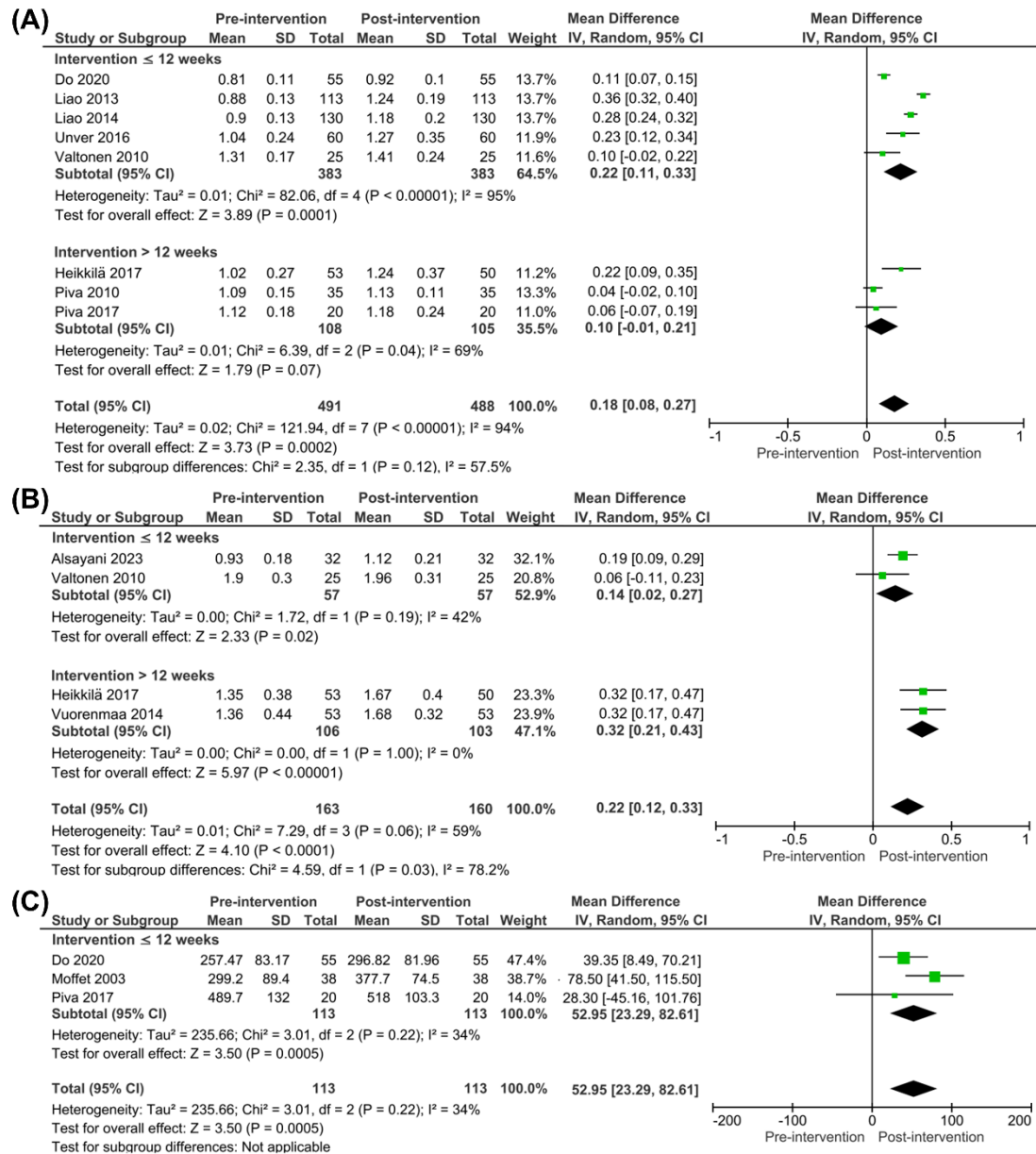


Fig. 3 Forest plots showing mean differences with 95% confidence intervals for changes in gait parameters following later-stage exercise interventions: **(A)** normal walking speed; **(B)** maximum walking speed; and **(C)** walking distance

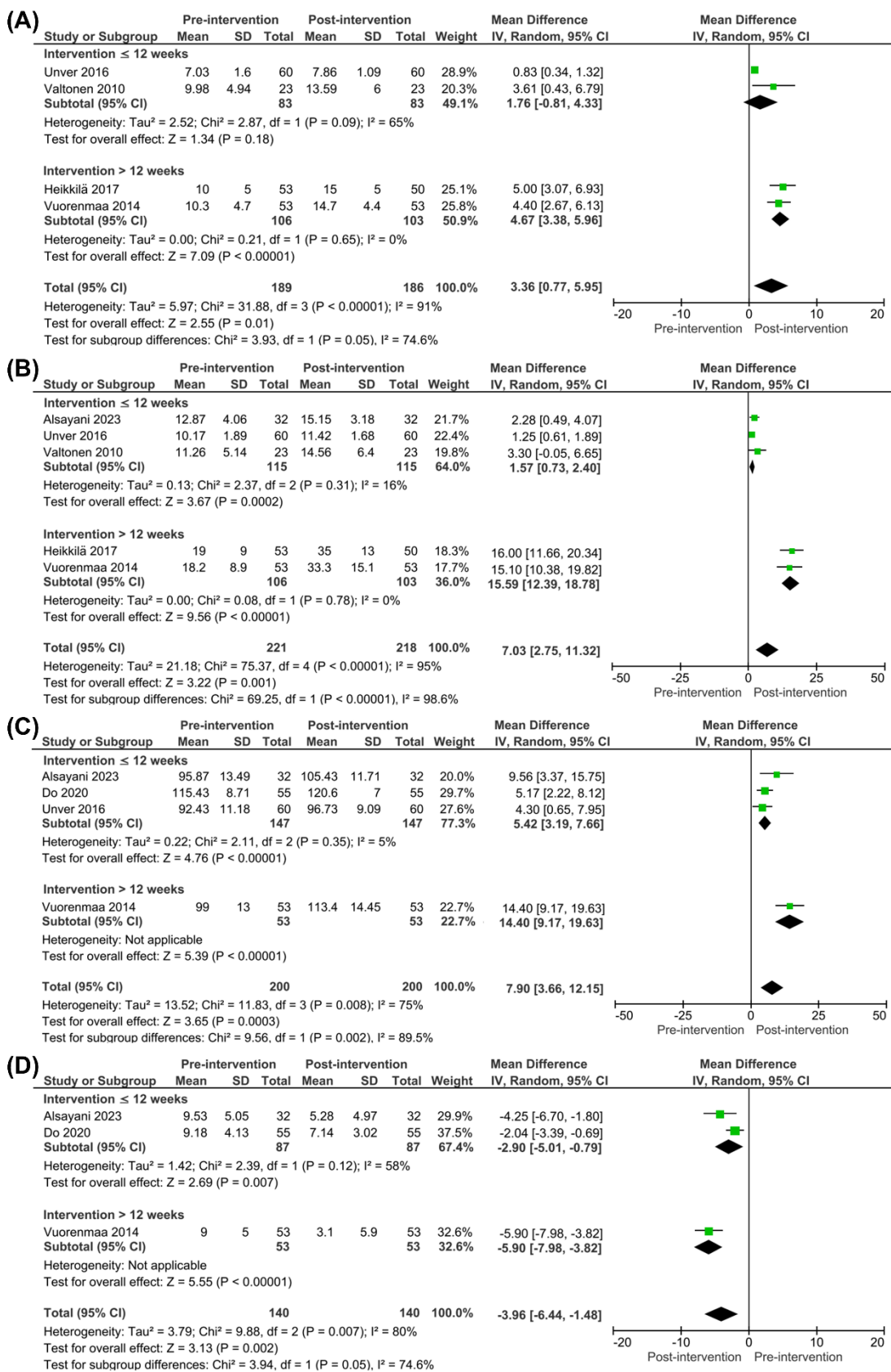


Fig. 4 Forest plots showing mean differences with 95% confidence intervals for changes in knee muscle strength and range of motion following later-stage exercise interventions: (A) knee flexor; (B) knee extensor; (C) knee flexion angle; and (D) knee extension angle

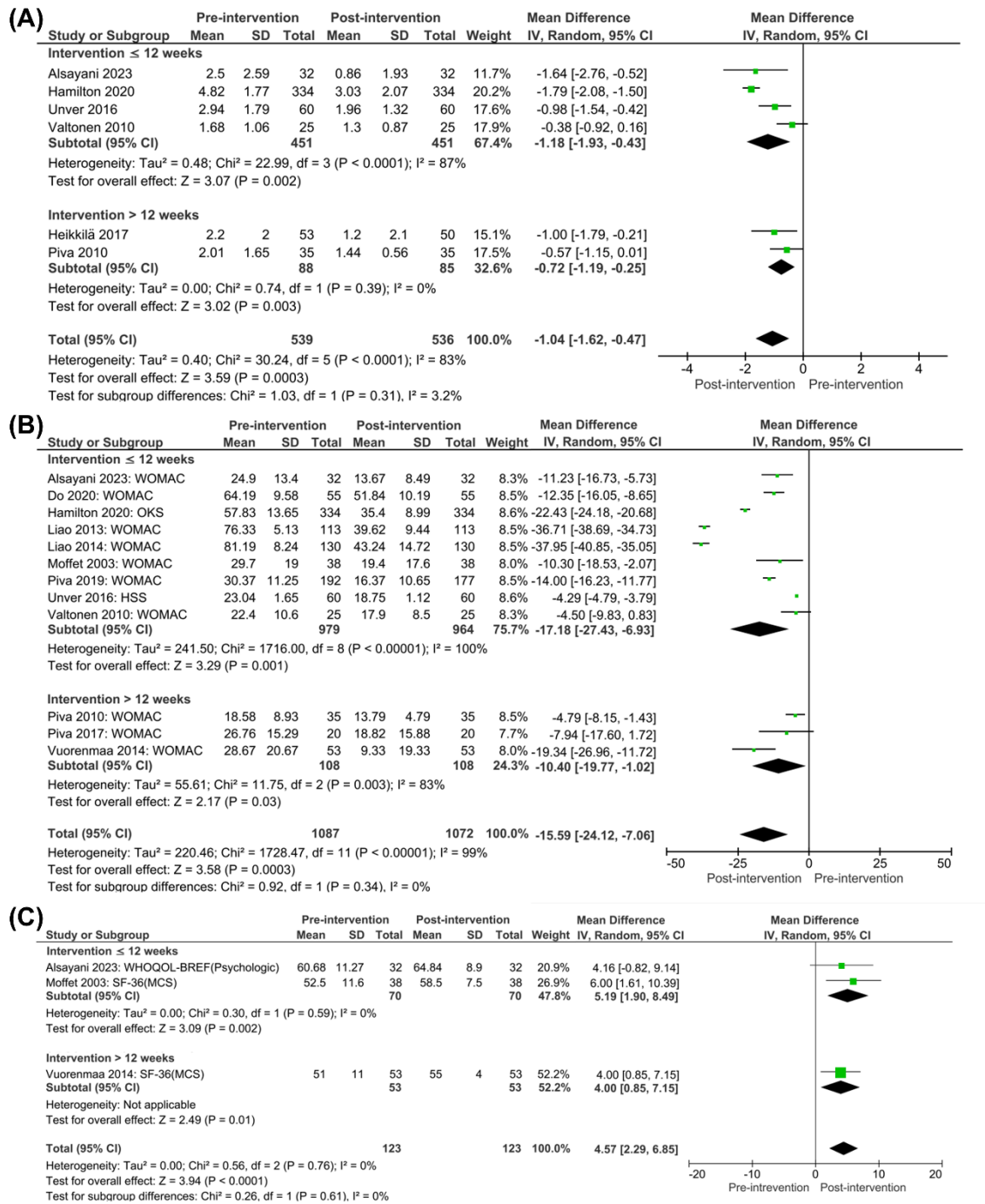


Fig. 5. Forest plots showing mean differences with 95% confidence intervals for changes in subjective outcome following later-stage exercise interventions: **(A)** pain intensity; **(B)** disability score; and **(C)** mental status.

Abbreviations: 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.

Table legends

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	<i>Objective outcomes:</i> Functional performance, muscle strength, range of motion, or other variables related to knee outcome measures. <i>Subjective outcomes:</i> Pain intensity, disability score, mental status, or other patient-reported variables related to knee outcome measures.

Table 2 Summary of the fifteen included studies

Study	Population	Exercise Intervention			Outcomes	
		Descriptions	Dosage	TIDieR Score (0 – 100)	Significant Changes	No Significance
Alsayani 2023	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)↑	
Do 2020	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↓ 2) Knee range of motion • Knee flexion angle↑ • Knee extension angle↓ Subjective outcomes: 1) Disability score • WOMAC↓	Objective outcomes: 1) Gait parameter • Stride length

Study	Population	Exercise Intervention			Outcomes	
		Descriptions	Dosage	TIDieR Score (0 – 100)	Significant Changes	No Significance
Hamilton 2020	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
Heikkilä 2017	N: 50 Age: 69.00±8.00 Time since surgery: ≥ 2 months Operated leg: Unilateral and bilateral legs Primary TKA: Yes	Home-based exercise: 1) Strengthening exercises • Knee flexor • Knee extensor 2) Functional training • Sit-to-stand • Stepping • Squatting 3) Stretching exercises • Knee 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

Study	Population	Exercise Intervention			Outcomes	
		Descriptions	Dosage	TIDieR Score (0 – 100)	Significant Changes	No Significance
Hsu 2019	Surgical method identification: Yes	• Knee extensor • Hip flexor • Ankle plantar-flexor				
	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
Liao 2013	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	>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
Liao 2014	N: 130 Age: 72.41±6.68 Time since surgery: ≥ 2 months Operated leg: Unilateral leg Primary TKA: Yes Surgical method identification: Yes	• Cross-over steps • Tandem walk • Multidirectional walk 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↓	
Moffet 2003	N: 38 Age: 66.70±8.70 Time since surgery: ≥ 2 months Operated leg: Unilateral leg	Supervised and home-based exercise: 1) Strengthening exercises • Knee flexor • Knee extensor • Hip abductor 2) Functional training • Sit-to-stand • Stair climbing • Walking	>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)

Study	Population	Exercise Intervention			Outcomes	
		Descriptions	Dosage	TIDieR Score (0 – 100)	Significant Changes	No Significance
Piva 2010	Primary TKA: Yes Surgical method identification: N/A	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				
	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	>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↑	

Study	Population	Exercise Intervention			Outcomes	
		Descriptions	Dosage	TIDieR Score (0 – 100)	Significant Changes	No Significance
Piva 2017	N: 20 Age: 68.30±5.50 Time since surgery: ≥ 3 months Operated leg: Unilateral leg Primary TKA: N/A Surgical method identification: Yes	• Shuttle walk • Multidirectional walk 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
Piva 2019	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)
Smith 2019	N: 24 Age: 64.50±8.20 Time since surgery: ≥ 10 months	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↓	Objective outcomes: 1) Knee range of motion • Knee flexion angle 2) Vital sign • Heart rate 3) Anthropometrics • Body weight

Study	Population	Exercise Intervention			Outcomes	
		Descriptions	Dosage	TIDieR Score (0 – 100)	Significant Changes	No Significance
	Operated leg: N/A Primary TKA: N/A Surgical method identification: N/A				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)↑	• Body mass index Subjective outcomes: 1) Mental status • SF-36(MCS)
Unver 2016	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↑	
Valtonen 2010	N: 25 Age: 65.80±6.20 Time since surgery: ≥ 4 months Operated leg: Unilateral leg Primary TKA: Yes Surgical method identification:	Supervised exercises: 1) Strengthening exercises • Knee flexor • Knee extensor • Hip flexor • Hip extensor • Hip abductor • Hip adductor 2) Functional training • Walking	>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	Objective outcomes: 1) Gait parameter • Maximum gait speed Subjective outcomes: 1) Pain intensity • VAS 2) Disability score • WOMAC

Study	Population	Exercise Intervention			Outcomes	
		Descriptions	Dosage	TIDieR Score (0 – 100)	Significant Changes	No Significance
	Yes	• Jogging • Squatting			• Thigh muscles↑	
Vuorenmaa 2014	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

Abbreviations: 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.

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

Outcomes	Later-stage exercise interventions			Subgroup differences	MDC ^a
	Overall	≤12 weeks	>12 weeks		
<i>Objective outcomes</i>					
<u>Functional performance</u>					
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
<u>Gait parameter</u>					
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
<u>Muscle strength</u>					
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
<u>Range of motion</u>					
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
<i>Subjective outcomes</i>					
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).

Abbreviations: 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.

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

Abbreviations: 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.

Supplementary Materials

Supplementary Material 1 Search strategy in each database

Databases	Search strategy
PubMed (n = 816)	(("knee arthroplasty"[Title/Abstract]) OR ("knee replacement"[Title/Abstract])) AND (("exercise"[Title/Abstract]) OR ("training"[Title/Abstract])) AND (("pain"[Title/Abstract]) OR ("disability"[Title/Abstract]) OR ("anxiety"[Title/Abstract]) OR ("depress*"[Title/Abstract]) OR ("mental"[Title/Abstract]) OR ("psycho*"[Title/Abstract]) OR ("stress"[Title/Abstract]) OR ("function*"[Title/Abstract])) AND (english[Filter])
Scopus (n = 1,750)	(TITLE-ABS-KEY ("knee arthroplasty") OR TITLE-ABS-KEY ("knee replacement")) AND (TITLE-ABS-KEY ("exercise") OR TITLE-ABS-KEY ("training")) AND (TITLE-ABS-KEY ("pain") OR TITLE-ABS-KEY ("disability") OR TITLE-ABS-KEY ("anxiety") OR TITLE-ABS-KEY ("depress*") OR TITLE-ABS-KEY ("mental") OR TITLE-ABS-KEY ("psycho*") OR TITLE-ABS-KEY ("stress") OR TITLE-ABS-KEY ("function*")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE , "English"))
Web of Science (n = 681)	(((AB=("knee arthroplasty")) OR (TI=("knee arthroplasty")))) OR ((AB=("knee replacement")) OR (TI=("knee replacement")))) AND (((AB=("exercise")) OR (TI=("exercise")))) OR ((AB=("training")) OR (TI=("training")))) AND (((AB=("pain")) OR (TI=("pain")))) OR ((AB=("disability")) OR (TI=("disability")))) OR ((AB=("anxiety")) OR (TI=("anxiety")))) OR ((AB=("depress*")) OR (TI=("depress*")))) OR ((AB=("mental")) OR (TI=("mental")))) OR ((AB=("psycho*")) OR (TI=("psycho*")))) OR ((AB=("stress")) OR (TI=("stress")))) OR ((AB=("function*")) OR (TI=("function*")))) and Article (Document Types) and English (Languages)

Supplementary Material 2 Template for intervention description and replication
(TIDieR)

Items	Descriptions
1. Brief name	Provide the name or a phrase that describes the intervention.
2. Why	Describe any rationale, theory or goal of the elements essential to the intervention.
3. What (materials)	Describe any physical or information materials used in the intervention, including those provided to participants or used in intervention delivery or in training of intervention providers. Provide information on where the materials can be accessed (for example, online, appendix, URL).
4. What (procedures)	Describe each of the procedures, activities, and/or processes used in the intervention, including any enabling or support activities.
5. Who provided	For each category of intervention provider (for example, psychologist, nursing assistant), describe their expertise, background and any specific training given
6. How	Describe the modes of delivery (such as face-to-face or by some other mechanism, such as internet or telephone) of the intervention and whether it was provided individually or in a group.
7. Where	Describe the type(s) of location(s) where the intervention occurred, including any necessary infrastructure or relevant features.
8. When and how much	Describe the number of times the intervention was delivered and over what period including the number of sessions, their schedule, and their duration, intensity or dose
9. Tailoring	Is the intervention was planned to be personalized, titrated or adapted, then describe what, why, when and how.
10. Modifications	If the intervention was modified during the study, describe the changes (what, why, when and how).
11. How well (planned)	If intervention adherence or fidelity was assessed, describe how and by whom, and if any strategies were used to maintain or improve fidelity, describe them.
12. How well (actual)	If intervention adherence or fidelity was assessed, describe the extent to which the intervention was delivered as planned.

Supplementary Material 3 Risk of bias in the fifteen included studies

Physiotherapy Evidence Database (PEDro) scale											
Study	Random Allocation	Concealed Allocation	Baseline Comparability	Participant Blinding	Therapist Blinding	Assessor Blinding	> 85% Follow-up	Intention-to-treat Analysis	Between-group Comparisons	Point Estimates and Variability	Total (0 to 10)
Alsayani 2023	Y	N	Y	N	N	Y	N	N	Y	Y	5
Do 2020	Y	Y	Y	N	N	Y	Y	Y	Y	Y	8
Hamilton 2020	Y	N	Y	N	N	Y	Y	Y	Y	Y	7
Heikkilä 2017	Y	N	Y	N	N	Y	Y	N	Y	Y	6
Hsu 2019	N	N	Y	N	N	N	N	N	Y	Y	3
Liao 2013	Y	Y	Y	N	N	Y	Y	N	Y	Y	7
Liao 2014	Y	N	Y	N	N	Y	Y	Y	Y	Y	7
Moffet 2003	Y	Y	Y	N	N	Y	Y	N	Y	Y	7
Piva 2010	Y	Y	Y	N	N	Y	N	N	Y	Y	6
Piva 2017	Y	Y	Y	N	N	Y	Y	N	Y	Y	7
Piva 2019	Y	Y	Y	Y	N	N	Y	N	Y	Y	7
Smith 2019	Y	N	Y	N	N	N	N	N	N	N	2
Unver 2016	Y	N	Y	N	N	N	N	N	Y	Y	4
Valtonen 2010	Y	Y	Y	N	N	N	Y	Y	Y	Y	7
Vuorenmaa 2014	Y	Y	Y	N	N	Y	Y	Y	Y	Y	8
Total											6.07±1.79

Abbreviations: N, absent; Y, present.

Supplementary Material 4 Summary of exercise types based on duration of later-stage exercise

Duration of later-stage exercise	Type of exercise (n, %)					
	Strengthening exercises	Functional training	Stretching exercises	Range of motion exercises	Endurance training	Balance training
≤12 weeks (n = 9)	9, 100%	7, 78%	6, 67%	6, 67%	5, 56%	3, 33%
>12 weeks (n = 6)	5, 83%	3, 50%	4, 67%	2, 33%	3, 50%	1, 17%

Supplementary Material 5 Completeness of the intervention descriptions in the fifteen included studies

Study	Template for Intervention Description and Replication (TIDieR)												Total (%)
	Brief Name	Why	How	Who Provided	What (materials)	When and How Much	What (procedures)	Where	Tailoring	Modifications	How Well (planned)	How Well (actual)	
Alsayani 2023	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	75%
Do 2020	Y	Y	N	Y	Y	Y	Y	Y	N	N	N	N	58%
Hamilton 2020	Y	Y	N	Y	Y	Y	Y	Y	Y	N	N	N	67%
Heikkilä 2017	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	75%
Hsu 2019	Y	Y	Y	Y	N	Y	Y	Y	Y	N	N	N	67%
Liao 2013	Y	Y	N	Y	Y	Y	Y	Y	Y	N	N	N	67%
Liao 2014	Y	Y	N	Y	Y	Y	Y	Y	Y	N	N	N	67%
Moffet 2003	Y	Y	N	Y	Y	Y	Y	Y	Y	N	N	N	67%
Piva 2010	Y	Y	N	Y	Y	Y	Y	Y	Y	N	N	N	67%
Piva 2017	Y	Y	N	Y	N	Y	Y	Y	Y	N	N	N	58%
Piva 2019	Y	Y	N	Y	Y	Y	Y	Y	Y	N	N	N	67%
Smith 2019	Y	Y	N	Y	N	Y	Y	Y	Y	N	N	N	58%
Unver 2016	Y	Y	N	Y	Y	Y	Y	Y	Y	N	N	N	67%
Valtonen 2010	Y	Y	N	Y	Y	Y	Y	Y	Y	N	N	N	67%
Vuorenmaa 2014	Y	Y	N	Y	Y	Y	Y	Y	Y	N	N	N	67%
Total													66%±5%

Abbreviations: N, absent; Y, present.

Supplementary Material 6 PRISMA 2020 Checklist

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	1
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	3–4
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	5–6
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	6
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	7, Table 1
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	7
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	7, Supplementary Material 1
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	7, Table 1
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	8
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	8, Table 1
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	8

Section and Topic	Item #	Checklist item	Location where item is reported
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	8
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	8
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	8
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	8
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	8
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	9
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	9
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	9
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	9
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	9, Fig. 1
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	9
Study characteristics	17	Cite each included study and present its characteristics.	10, Table 2
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	10, Supplementary Material 3
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	Table 2
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	11–16, Fig. 2–5

Section and Topic	Item #	Checklist item	Location where item is reported
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	11–16, Fig. 2–5
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	11–16, Fig. 2–5
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	10
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	Supplementary Material 3
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	16, Table 4
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	16–21
	23b	Discuss any limitations of the evidence included in the review.	20
	23c	Discuss any limitations of the review processes used.	20
	23d	Discuss implications of the results for practice, policy, and future research.	20–21
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	7
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	22
Competing interests	26	Declare any competing interests of review authors.	22
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	22