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Evaluation of the efficacy after Total Knee Arthroplasty by Gait analysis in patients with Knee Osteoarthritis: a meta-analysis

Xinfeng Yu[1], Rujie Zhuang[2*] and Peng Jin[1]

Abstract

Background Total knee replacement (TKA) is a frequent modality performed in patients with knee osteoarthritis (OA). The aim of this study was to perform a meta-analysis and systematic review to evaluate the efficacy after TKA by gait analysis in patients with OA.

Methods PubMed, EMBASE, the Cochrane library, and Web of Science were searched for relevant studies from inception to July 2024. STATA SE 14.0 software was used for statistical analysis according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guideline.

Results A total of 2525 reports were identified with 24 studies meeting pre-designed inclusion criteria. Several gait parameters were investigated. In patients with knee OA after TKA, there existed an increase in the Max knee flexion (WMD, 3.12; 95% CI, 0.93 to 5.32; $I^2=73.9\%$, $P<0.001$), the Cadence (WMD, 4.05; 95% CI, 2.28 to 5.82; $I^2=48.9\%$, $P=0.068$), the stride length (WMD, 0.05; 95% CI, 0.01 to 0.09; $I^2=77.1\%$, $P<0.001$), the walking speed (WMD, 0.08; 95% CI, 0.02 to 0.14; $I^2=93.3\%$, $P<0.001$), and the step length (WMD, 0.04; 95% CI, 0.00 to 0.07; $I^2=89.3\%$, $P<0.001$) while a decrease in the double support time (WMD, -0.04; 95% CI, −0.08 to -0.01; $I^2=0.0\%$, $P=0.585$). Besides, no statistically significant differences were observed in the Knee range of motion (ROM), the Max knee rotation at stance phase, the Max knee extension, the step width, the stride time and the step time. Sensitivity analysis showed that all the results were robust.

Conclusions In summary, the study found that, in patients with knee OA undergoing TKA may have great effects on improving gait parameters. If there are more high-quality studies in the future, we should make a more comprehensive evaluation of walking function by gait analysis together with other evaluation systems such as muscle strength and proprioception measurement.

Keywords Total knee arthroplasty, Gait analysis, Knee osteoarthritis, Meta-analysis

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Background

Osteoarthritis (OA) is a common degenerative disease of cartilage, which is characterized by articular cartilage destruction, joint space stenosis and periarticular osteophyte proliferation [1, 2], as well as subchondral bone remodeling [3], meniscal degeneration [4, 5] and inflammation and fibrosis of both infrapatellar fat pad and synovial membrane [6]. It is the most common independent cause of the disability related to activities in the elderly population [7]. The number of female patients is more than the male [8]. Among all of OA, the incidence of knee OA is the highest [9]. With the walking and some heavy-load behaviors, pain, gradually increasing load in the joint cavity, persistent wear of the joints, and even complete loss of joint function are foreseeable and inevitable [10–12]. In recent years, total knee replacement (TKA) has been widely selected by patients with knee OA. According to the statistics of the National Registry [13], the number of TKA worldwide continued to increase every year. It was estimated that the demand for TKA would increase to 3.4 million cases per year by 2030 in the United States. In recent decades, people's recognition and acceptance of TKA on such a large scale was closely related to its obvious improvement of pain, accurate restoration of anatomical alignment of tibiofemoral joints, considerable prosthesis survival rate in medium or long-term follow-up [14–16] and satisfactory joint reconstruction effects [10–12]. Moreover, the continuous improvement of knee prosthesis [12] and the emergence of robot-assisted technology [14] also made people look forward to the future of TKA.

Six months after TKA is a critical period for patients with knee OA to recover knee joint function [14, 17]. During this period, doctors not only evaluate the functional capacity of knee joint through clinical scoring system and imaging examination [12], but also analyze gait abnormalities. Nowadays, gait analysis system [14, 18] can accurately reflect the small changes of joint motion, give objective values, and avoid the interference of subjective factors. It is a real, objective, accurate method to realize the evaluation of knee joint function. Once used, this quantifiable tool has been recognized by clinicians, and gradually applied to the evaluation of TKA in recent years, which is used to determine the decline of posture stability and gait change of patients due to the loss of proprioception [19, 20], thus helping surgeons find defects in the rehabilitation process, guiding personalized functional trainings and preventing the occurrence of compensation mechanisms [21].

Over several years, a lot of studies [14, 22–25] had analyzed gait parameters in patients with knee OA after TKA, but most of them were cohort studies. So far, only two meta-analyses were related to patients with knee OA receiving TKA. One study [26] was to discuss how long it will take to exercise after TKA to significantly improve the physical function of patients with knee OA, and the other [27] was to discuss the improvement of walking speed in patients with knee OA after TKA. The purpose of the former had nothing to do with gait parameters, while the latter only discussed one parameter and it was published 12 years ago (in 2012). Therefore, the purpose of this meta-analysis is to evaluate the effects of TKA in patients with knee OA by analyzing several gait parameters.

Materials and methods

The present systematic review with meta-analysis was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guideline [28].

Search strategy

PubMed, EMBASE, the Cochrane library, and Web of Science database were comprehensively searched for relevant studies from their inception until July 2024. The study used the medical subject heading (MeSH) term of 'Knee Osteoarthritides' 'Knee Osteoarthritis' 'Osteoarthritis of Knee' 'Gait Analysis' 'Knee Replacement Arthroplasties' and 'Knee Arthroplasty' as well as relevant keywords to develop the search strategy. The detailed search strategy of targeted English databases is summarized in Table S1.

Inclusion and exclusion criteria

Inclusion and exclusion criteria in the present study were based on the Population, Intervention, Comparator, Outcomes, and Study designs (PICOS) structure.

1. Population: patients with knee osteoarthritis.
2. Intervention: after total knee arthroplasty.
3. Comparator: before total knee arthroplasty.
4.Outcome: gait parameters: double support time, max knee extension, max knee flexion, knee range of motion (ROM), max knee rotation at stance phase, cadence, step length, step width, stride length, stride time, walking speed.
5. Study design: retrospective studies, prospective studies, cross-sectional studies, case-control studies and randomized controlled trials.

The exclusion criteria were as follows: (1) no original data were included (e.g., conference abstracts, case reports, and reviews); (2) repeated reports; (3) studies with incomplete data; (4) animal research; (5) patients with other diseases which influences the gait analysis.

Data extraction

Eligible studies were selected by two reviewers independently, which included screening titles and abstracts and checking full texts. Disagreements between them were resolved by consulting with a third one. The following data were extracted from included studies: author's name, publication year, country, sample size, age, female%, BMI, surgical approach, gait analysis system, study design, and surgical methods.

Quality assessment

The Methodological Index for Non-Randomized Studies (MINORS) [29] was used to assess the methodological quality of non-randomized studies. This tool consisted of 8 criteria for non-randomized studies and 4 added criteria specifically for comparative studies. The items were scored as follows: 0 (not reported), 1 (reported but inadequate), or 2 (reported and adequate). The global ideal score was set as 16 for non-comparative (non-randomized studies) and 24 for comparative studies. The revised Cochrane risk of bias tool for randomized trials (RoB 2) was performed to assess the quality of randomized studies [30]. Each included study was assessed in five domains including randomization process, deviations from intended interventions, missing outcome data, measurement of the outcome and selection of the reported result. Overall bias was defined as "low risk of bias" if all domains were rated as low risk, "some concerns" if at least one domain was rated as having some concerns, and "high risk of bias" if one or more domains rated as high risk or multiple domains were rated as having some concerns that might affect the validity of the results.

Statistical analysis

The meta-analysis was performed using the STATA SE 14.0 software (StataCorp, College Station, Texas, USA). Weight mean difference (WMD) and 95% confidence intervals (CIs) were used to assess results containing double support time, max knee extension, max knee flexion, knee ROM, max knee rotation at stance phase, cadence, step length, step width, stride length, stride time, walking speed. The study used χ^2 and I-squared (I^2) to evaluate the heterogeneity. The random-effect model was adopted if the $p \leq 0.10$ and $I^2 \geq 50\%$, which meant existing heterogeneity among studies model [31]. Otherwise, the fixed-effect model was applied. Publication bias was assessed using funnel plots, the Begg rank correlation [32] and egger weighted regression [33]. If significant bias was present, trim-and-fill analysis was used to judge whether the publication bias had an impact on the outcomes [34]. Subgroup analysis was used to explore possible sources of heterogeneity if necessary. Sensitivity analysis by leave-one-out method was used to test the robustness of the results [35]. $P < 0.05$ indicated statistical significance.

Results

Study selection

In summary, a total of 2757 studies were retrieved as potentially relevant literature reports through the initial searches in the above-mentioned databases. After the initial removal of 930 duplicate records, 1847 literatures were excluded after reviewing the title or abstract. After retrieving 36 full-length manuscripts, ultimately, 26 studies were eligible for data extraction and meta-analysis [10–12, 14, 17, 22–25, 36–52]. The flow chart of the studies enrolled in the current study can be found in Fig. 1.

Study characteristics

The twenty-six studies that met the inclusion criteria were published between 2005 and 2024, with sample sizes ranged from 8 to 118. The studies were conducted in one each in America, Austria, Australia, China, Germany, Hungary, India, Korea, Netherlands, Norway, Poland and Turkey, as well as two in Canada, Greece, Japan, three in England and five in Switzerland. The majority of the study population were middle or elderly age. Female% ranged from 37.5 to 100. The participants' demographic characteristics in the included studies can be found in Table 1.

Quality assessment

Quality assessment was performed among each included non-randomized studies by MINORS and each included randomized controlled trials (RCTs) by RoB2. The results of the included non-randomized studies were at moderate risk, which may result from the high risk of non-blinding (total knee arthroplasty) (Table 2) and included RCTs were at low risk (Fig. 2).

Max Knee Flexion

After total knee arthroplasty (TKA), there was a significant increase in the maximum knee flexion angle (WMD = 3.12; 95% CI, 0.93 to 5.32; I^2 = 73.9%, $P < 0.001$), indicating improved knee flexion range (Fig. 3A). Considering high heterogeneity, the subgroup analysis was performed. Patients with BMI < 30 had a WMD of 5.54 (95% CI, -0.22 to 11.30; I^2 = 88.1%, $P < 0.001$), while those with BMI ≥ 30 had a WMD of 1.91 (95% CI, -0.41 to 4.23; I^2 = 58.7%, $P = 0.064$) (Supplementary Fig. 1A). For follow-up duration, the WMD was 5.25 (95% CI, -0.56 to 11.06; I^2 = 88.2%, $P < 0.001$) in the <1 year group, and 2.53 (95% CI, 1.19 to 3.86; I^2 = 0.0%, $P = 0.873$) in the ≥1 year group. The results were significant for patients with follow-up ≥1 year but not for other subgroups (Supplementary Fig. 1B).

Cadence

Post-TKA, cadence showed a significant increase (WMD = 4.05; 95% CI, 2.28 to 5.82; I^2 = 48.9%, $P = 0.068$),

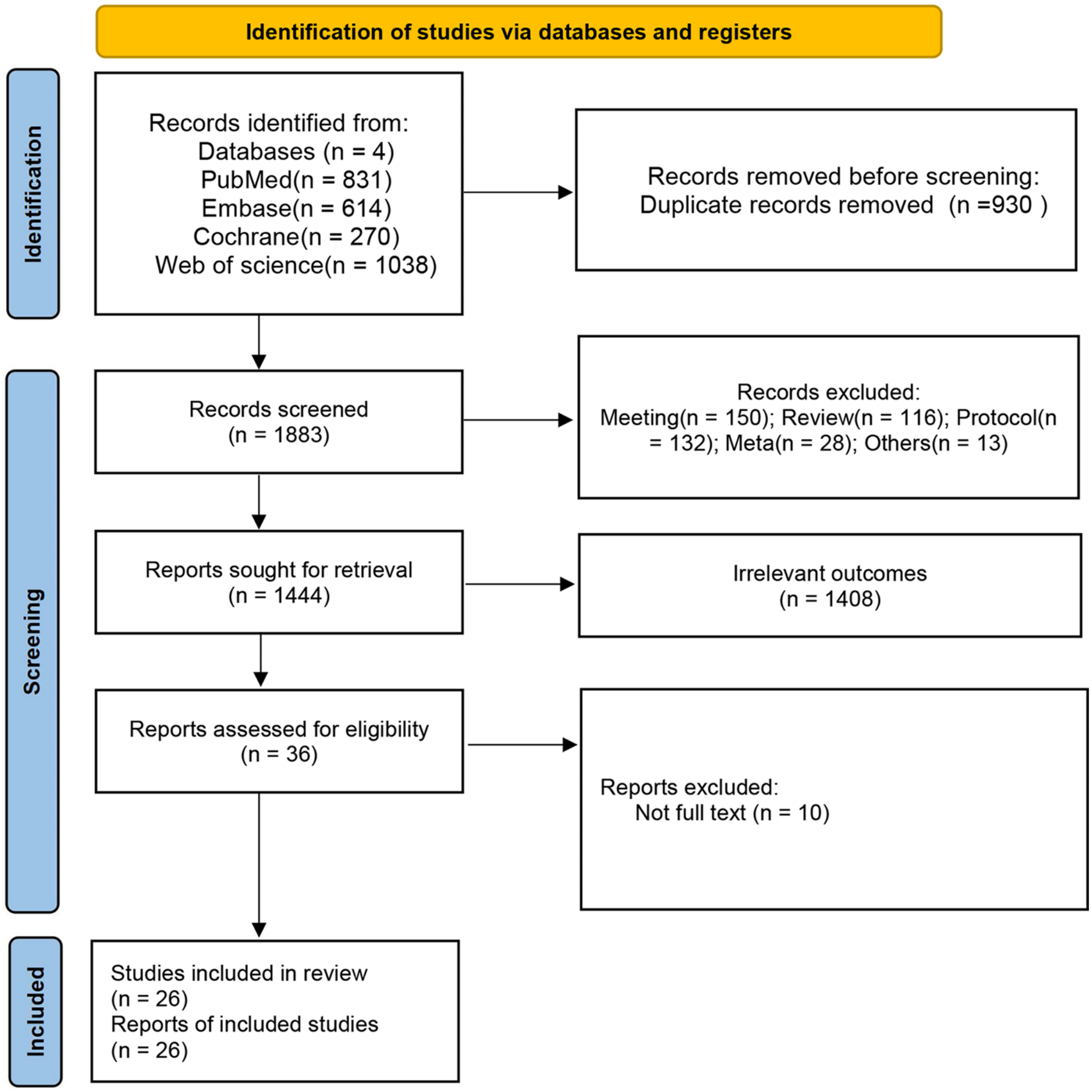

Fig. 1 PRISMA flow chart for study screening and inclusion

indicating significantly improved walking rhythm (Fig. 3B).

Stride length

Following TKA, stride length significantly increased (WMD=0.05; 95% CI, 0.02 to 0.09; I^2 = 74.1%, P<0.001), suggesting enhanced walking stride (Fig. 3C). Subgroup analysis showed that patients with BMI≥30 had a WMD of 0.03 (95% CI, -0.03 to 0.09; I^2 = 85.1%, P<0.001), while those with BMI<30 had a significant WMD of 0.05 (95% CI, 0.01 to 0.09; I^2 =0.0%, P=0.523), demonstrating a significant increase (Supplementary Fig. 2A). For follow-up duration, the WMD was 0.07 (95% CI, 0.04 to 0.10; I^2 = 42.5%, P=0.095) in the ≥1 year group, demonstrating a significant increase, whereas the <1 year group had a WMD of 0.01 (95% CI, -0.04 to 0.07; I^2 =48.8%, P=0.099), showing no significant change (Supplementary Fig. 2B).

Walking speed

Walking speed exhibited a significant increase post-TKA (WMD=0.08; 95% CI, 0.02 to 0.14; I^2 = 93.3%, P<0.001), indicating improved gait speed (Fig. 3D). Subgroup analysis revealed a WMD of 0.13 (95% CI, 0.04 to 0.22; I^2 = 94.9%, P<0.001) for patients with BMI≥30, and a significant WMD of 0.04 (95% CI, -0.08 to 0.15; I^2 = 92.3%, P<0.001) for those with BMI<30 (Supplementary Fig. 3A). For follow-up duration, the ≥1 year group showed a significant WMD of 0.13 (95% CI, 0.06 to 0.20; I^2 = 87.2%, P<0.001), while the <1 year group had a non-significant WMD of 0.03 (95% CI, -0.04 to 0.10; I^2 = 89.2%, P<0.001) (Supplementary Fig. 3B).

Step length

Step length saw a significant increase following TKA (WMD=0.01; 95% CI, -0.04 to 0.06; I^2 = 95.1%, P<0.001)

Table 1 Baseline characteristics of 26 included studies

Study ID	Country	Simple size	study design	Surgical methods	Age (years old)	Gender, female, *n* (%)	BMI (kg/m^2)	Gait analysis system	Surgical Approach	Follow-up duration
He 2023 [14]	China	31	Retrospective study	Unilateral TKA	66.1	80.65	25.9	Vicon 3D gait capture system	A median anterior knee incision with the medial patellar approach	Pre-TKA, 3 and 6 months post-TKA
Solak 2005 [12]	Turkey	24	Retrospective study	Bilateral TKA	67	100	31.25	The Natural Knee System	NA	Pre-TKA, 12 and 24 months post-TKA
Tibesku 2011 [11]	Germany	16	RCT	Unilateral TKA	NA	56.25	NA	a six camera motion analysis system synchronized with two force platforms	standard medial parapatellar approach	Pre-TKA and 24 months post-TKA
Urwin 2014 [10]	England	8	Retrospective study	Unilateral TKA	59.6	37.5	31.92	Three dimensional motion analysis system	NA	Pre-TKA and 9 months post-TKA
Wang 2021 [36]	Norway	23	Retrospective study	Unilateral and bilateral TKA	67	56.52	31.1	the Vicon Plug-in-Gait (lower body) marker system	NA	Pre-TKA, 3, 6 and 12 months post-TKA
Baczkowicz 2018 [17]	Poland	21	Retrospective study	Unilateral TKA	63.5	66.7	29.1	the GAITRite portable pressure-sensitive walkway	standard medial parapatellar approach	Pre-TKA, 5 days, and 3 weeks post-TKA
Fransen 2022 [37]	Netherlands	38	Retrospective study	Unilateral TKA	69	47	29	The Dutch version of the modified Gait Efficacy Scale	fast-track protocol	Pre-TKA and 3 months post-TKA
Alice 2015 [38]	Switzerland	90	Retrospective study	Unilateral TKA	68	NA	30.7	A 3D, 12-camera motion analysis system	standard medial parapatellar approach	Pre-TKA and 3 months post-TKA
Apostolopoulos 2011 [39]	Greece	20	Retrospective study	Unilateral TKA	69.6	56	31.23	A four-camera, 3D, Biokin 3D Motion Analysis System	NA	Pre-TKA and 9 months post-TKA
Apostolopoulos 2020 [40]	Greece	15	Retrospective study	Unilateral TKA	68.6	53.33	31.23	A four-camera, 3D, Biokin 3D Motion Analysis System	NA	Pre-TKA and 9 months post-TKA
Wilson 2015 [41]	Canada	52	Retrospective study	Unilateral TKA	64.67	53.85	32.59	a synchronized Optotrak 3020 motion capture system and an AMTI force platform	NA	Pre-TKA and 12 months post-TKA
Alice 2022 [42]	Switzerland	20	Retrospective study	Unilateral TKA	69	65	28.2	A 12-camera motion analysis system	standard medial parapatellar approach	Pre-TKA, 1 and 7 years post-TKA
Bejek 2011 [43]	Hungary	15	RCT	Unilateral TKA	67	46.67	27.22	a zebris CMS-HS, a computerized ultrasound-based motion analysis system	NA	Pre-TKA, 3, 6, 9, and 12 months post-TKA

Table 1 (continued)

Study ID	Country	Simple size	study design	Surgical methods	Age (years old)	Gender, female, *n* (%)	BMI (kg/m^2)	Gait analysis system	Surgical Approach	Follow-up duration
Bonnefoy 2017 [44]	Switzerland	118	Retrospective study	Unilateral TKA	68.7	59.32	30.7	three separate visits with a 12-camera motion analysis system	NA	Pre-TKA, 3 and 12 months post-TKA
Bonnefoy 2020 [45]	Switzerland	79	Retrospective study	Unilateral TKA	69	65	29.2	three separate visits with a 12-camera motion analysis system	NA	Pre-TKA and 12 months post-TKA
Hiyama 2015 [25]	Japan	43	Retrospective study	Unilateral TKA	72	81.4	25.9	A triaxial accelerometer	NA	Pre-TKA and 5 days post-TKA
Hatfield 2011 [46]	Canada	42	Retrospective study	Unilateral TKA	65	57.14	32.1	Optotrak 3020 motion capture system	intramedullary alignment with a 5° valgus distal femoral cut and a neutral (0°) tibial cut	Pre-TKA and 12 months post-TKA
Braito 2016 [47]	Austria	17	Retrospective study	Unilateral TKA	66.4	64.71	29.5	a 3D motion analysis system, using a 4-segment lower-body marker model	a medial mini-midvastus arthrotomy	Pre-TKA and 8 weeks post-TKA
Ro 2018 [48]	Korea	23	Retrospective study	Unilateral TKA	67.1	100	26.83	a Helen Hayes marker set placed on their body	NA	Pre-TKA and 24 months
Rahman 2015 [49]	England	28	Retrospective study	Unilateral TKA	66.9	56.76	29.9	Motion sensors	a medial peri-patellar approach	Pre-TKA and 12 months post-TKA
Quervain 2012 [24]	Switzerland	111	Prospective Study	Unilateral and bilateral TKA	67	69.37	28.57	A custom-made ultrasound device	NA	Pre-TKA and 24 months post-TKA
Mandeville 2008 [23]	America	21	Retrospective study	Unilateral TKA	63.7	71.43	32.9	an eight-camera motion analysis system	NA	Pre-TKA and 6 months post-TKA
Mine 2015 [22]	Japan	35	Retrospective study	Unilateral TKA	70	100	NA	a 3-dimensional motion analysis device	the parapatellar approach	Pre-TKA, 1 and 3 months post-TKA
Paterson 2018 [50]	Australia	43	Retrospective study	Unilateral TKA	70.3	58	30.8	a Vicon motion capture system	NA	re-TKA and 6 months post-TKA
Ajekigbe 2024 [51]	England	49	RCT	Unilateral and bilateral TKA	NA	NA	NA	Tekscan™ Walkway™ instrumented mat system	NA	Pre-TKA and 12 months post-TKA
Tanpure 2023 [52]	India	11	Retrospective study	Unilateral TKA	68	NA	NA	a 3D instrumented gait lab comprising nine Qualisys Oqus camera units	NA	Pre-TKA and 6 ~ 12 months post-TKA

Abbreviations NA: not available; RCT: randomized controlled trial; TKA: total knee arthroplasty

Table 2 Quality assessment of included non-randomized studies by MINORS

Study	1	2	3	4	5	6	7	8	9	10	11	12	Total
He 2023	2	2	2	2	2	2	2	2					16
Solak 2005	2	2	2	2	2	2	2	2	2	2	2	2	24
Urwin 2014	2	2	2	2	2	2	2	2					16
Wang 2021	2	2	2	2	2	2	2	2					16
Baczkowicz 2018	2	2	2	2	2	2	2	2					16
Fransen 2022	2	2	2	2	2	2	2	2					16
Alice 2015	2	2	2	2	2	2	2	2					16
Apostolopoulos 2011	2	2	2	2	2	2	2	2					16
Apostolopoulos 2020	2	2	2	2	2	2	2	2					16
Wilson 2015	2	2	2	2	2	2	2	2	2	2	2	2	24
Alice 2022	2	2	2	2	2	2	2	2					16
Bonnefoy 2017	2	2	2	2	2	2	2	2					16
Bonnefoy 2020	2	2	2	2	2	2	2	2					16
Hiyama 2015	2	2	2	2	2	0	2	2					14
Hatfield 2011	2	2	2	2	2	2	2	2					16
Braito 2016	2	2	2	2	2	2	2	2	2	2	2	2	24
Ro 2018	2	2	2	2	2	2	2	2					16
Rahman 2015	2	2	2	2	2	2	2	2					16
Quervain 2012	2	2	2	2	2	2	2	2					16
Mandeville 2008	2	2	2	2	2	2	2	2					16
Mine 2015	2	2	2	2	2	2	2	2	2	2	2	2	24
Paterson 2018	2	2	2	2	2	2	2	2					16
Tanpure 2023	2	2	2	2	2	2	2	2					16

(1) A stated aim of the study; (2) Inclusion of consecutive patients; (3) Prospective collection of data; (4) Endpoint appropriate to the study aim; (5) Unbiased evaluation of endpoints; (6) Follow-up period appropriate to the major endpoint; (7) Loss to follow up not exceeding 5%; (8) Prospective calculation of the sample size; (9) A control group having the gold standard intervention; (10) Contemporary groups; 11. Baseline equivalence of groups; 12. Statistical analyses adapted to the study design

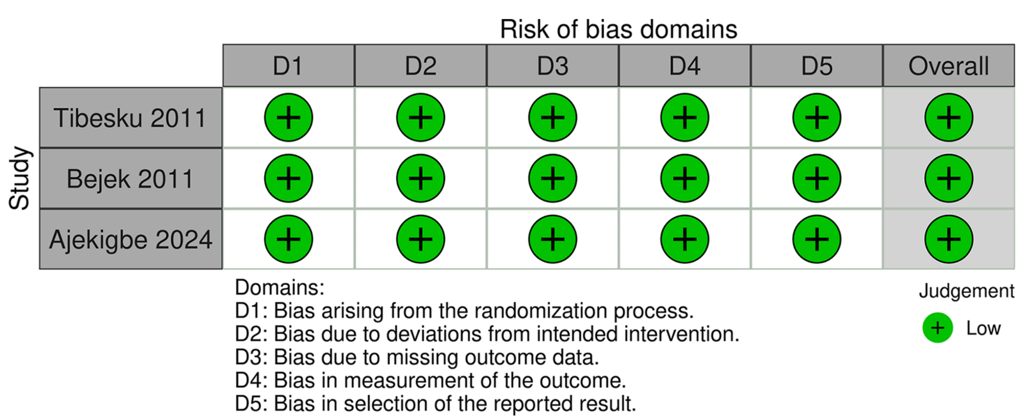

Fig. 2 RoB2 of included RCTs

(Fig. 3E). Subgroup analysis showed a WMD of 0.05 (95% CI, 0.00 to 0.10; I^2 = 92.9%, $P<0.001$) for patients with BMI≥30, and a significant WMD of 0.08 (95% CI, 0.02 to 0.14) for those with BMI<30 (Supplementary Fig. 4A). For follow-up duration, the ≥1 year group had a WMD of 0.04 (95% CI, -0.19 to 0.10; I^2 = 98.1%, $P<0.001$), which was not significant, while the <1 year group had a WMD of 0.03 (95% CI, 0.00 to 0.07; I^2 = 79.5%, $P<0.001$), also showing no significant change (Supplementary Fig. 4B).

Double support time

Double support time had a significant decrease following TKA (WMD = -0.05; 95% CI, -0.02 to -0.08; I^2 = 0.0%, P=0.719) (Fig. 3F), indicating significantly improved gait stability.

Other parameters

In addition, after TKA, there existed an increase trend in the knee ROM (WMD, 3.22; 95% CI, −5.48 to 11.91; I^2=92.9%, $P<0.001$) (Fig. 4A) and the Max knee rotation at stance phase (WMD, 6.11; 95% CI, −1.19 to 13.41;

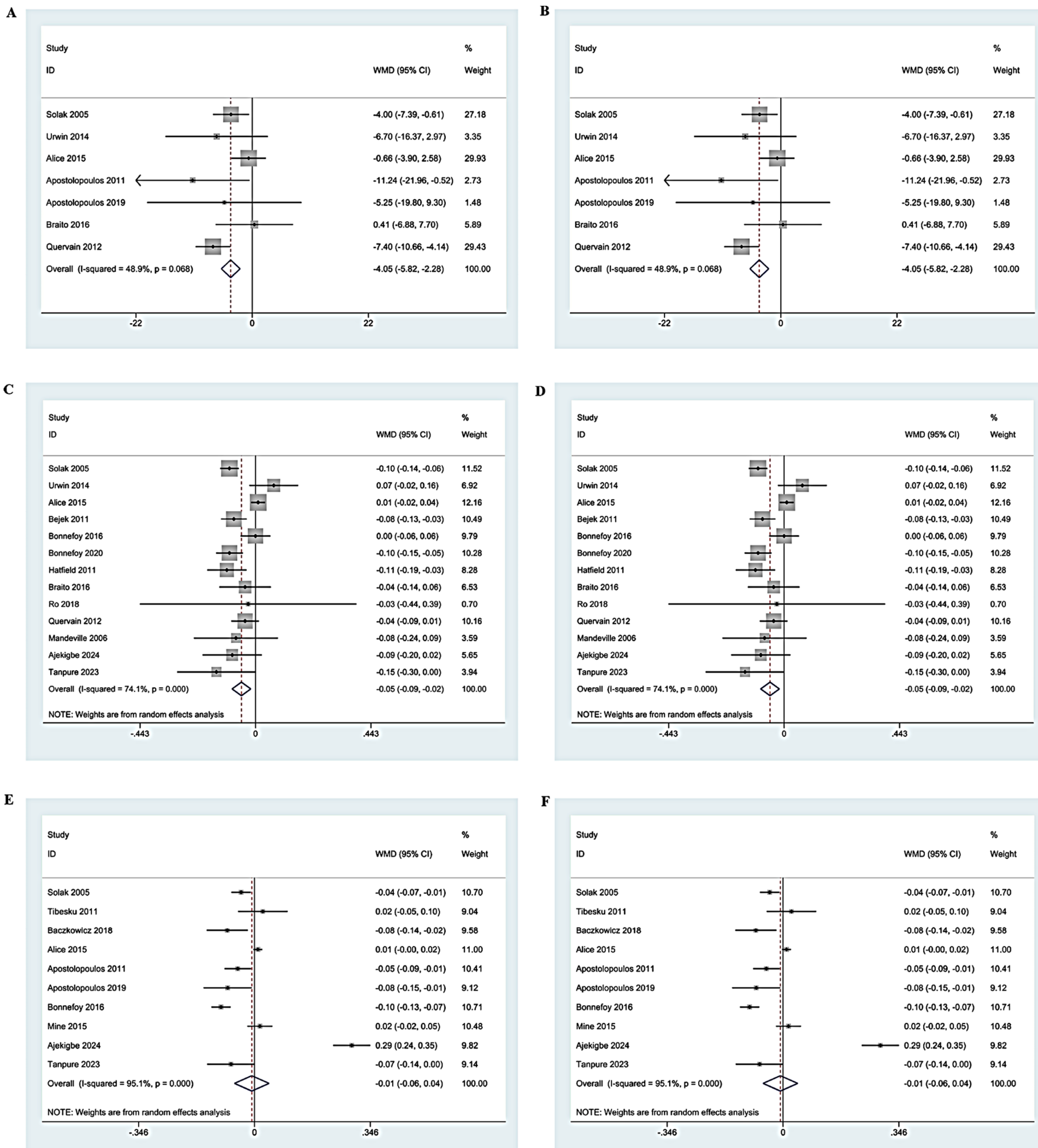

Fig. 3 Forest plot for gait parameters with significant differences. **A**) Max knee flexion; **B**) Cadence; **C**) Stride length; **D**) Walking speed; **E**) Step length; **F**) Double support time

I^2=98.1%, P<0.001) (Fig. 4B) while a decrease trend in the Max knee extension (WMD, -1.53; 95% CI, −7.73 to 4.67; I^2=90.3%, P=0.001) (Fig. 4C), the step width (WMD, 0.00; 95% CI, −0.01 to 0.01; I^2=24.6%, P=0.257) (Fig. 4D), the stride time (WMD, -0.06; 95% CI, -0.14 to 0.03; I^2=71.7%, P=0.007) (Fig. 4E), the step time (WMD, -0.03; 95% CI, -0.12 to 0.06; I^2=61.7%, P=0.106) (Fig. 4F). However no statistically significant differences were observed in these parameters.

Publication bias and sensitivity analysis

There was no significant publication bias for any of the outcome variables (double support time, max knee extension, max knee flexion, knee ROM, max knee rotation at stance phase, cadence, step length, step time, step width, stride length, stride time, walking speed) and the number of studies required, as evidenced by the visualization of funnel plot asymmetry and Begg and Egger's test (P>0.05) (Supplementary Tables 2 and Supplementary Fig. 5A-J). Finally, the sensitivity analysis indicated

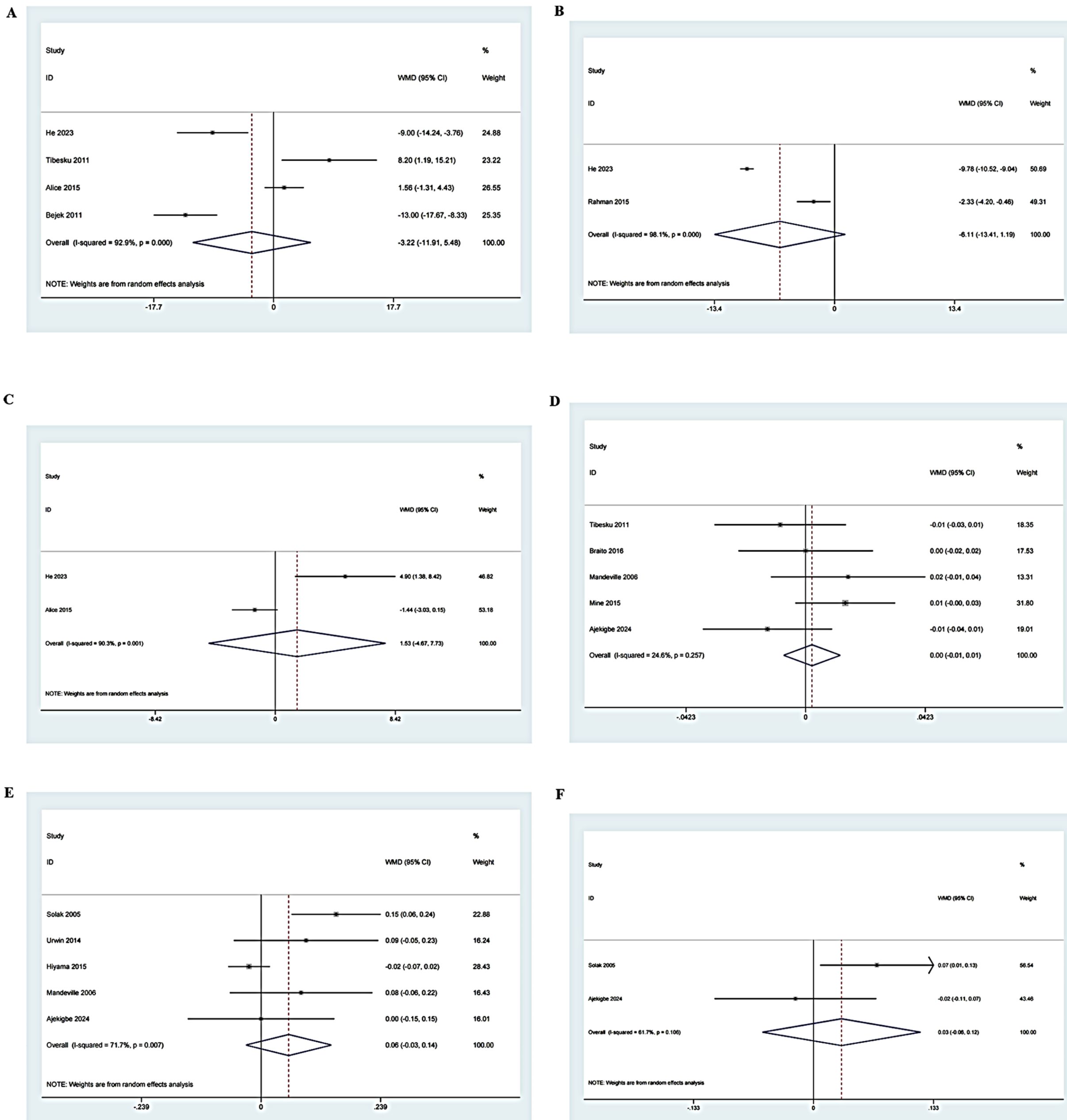

Fig. 4 Forest plot for gait parameters without significant differences. **A**) Knee ROM; **B**) Max knee rotation at stance phase; **C**) Max knee extension; **D**) Step width; **E**) Stride time; **F**) Step time

that no significant differences resulted from the omission of the data from any single study, suggesting that pooled effect size results were robust (Supplementary Fig. 6A-J).

Discussion

The meta-analysis, which included a comprehensive collection of 26 studies, revealed a significant difference before and after TKA in gait parameters in patients with knee OA. Compared with the preoperative, there existed an increase in the Max knee flexion, the Cadence, the stride length, the walking speed, and the step length statistically while a decrease in the double support time statistically after TKA. In addition, the subgroup analysis showed the high heterogeneity of several parameters may result from BMI or the follow-up.

Although there has been a great breakthrough in prosthesis design and intraoperative auxiliary methods of TKA in recent years, many patients are not satisfied with the recovery of postoperative function (or have higher expectations) [53]. The reason for this phenomenon may be that patients always want to restore barrier-free limb movements rather than just medical local joint correction [14, 54, 55]. Gait analysis, as an objective tool that only depends on equipment measurement [14, 54, 56], increases the objective weight of evaluation, and makes both doctors and patients reach a basic agreement on the evaluation standard of postoperative recoveries, which is helpful for effective doctor-patient communications. Clinically, gait parameters [11, 12, 14] that we often discussed include spatio-temporal parameters (such as Walking speed, Cadence, Step length, Step width, Stride length, Stride time, Double support time) and kinematics parameters (Knerom, Max knee extension, Max knee flexion, Max knee rotation at stance phase). For patients with knee OA after TKA, the ROM of knee increased during walking [14], indicating the improvement of pain and stiffness, and the improvement of walking efficiency. The higher the degree of knee joint extension is, the better the improvement of flexion contracture is, and the fatigue of quadriceps femoris in standing position is also improved [10, 17, 36]. The recovery of knee flexion can make patients avoid compensatory movement in pelvis [11, 57]. As for spatio-temporal parameters, excluding the influencing factors such as gender, personal walking habits and prosthesis loosening, the increase of step length and walking speed, the stable walking rhythm and the decrease of double support time all indicate the improvement of walking function and the recovery of balance control [39, 40, 47]. Therefore, we evaluated the effect of TKA in patients with knee OA by analyzing several gait parameters.

In 2012, there was a meta-analysis [27] to study the improvement of a gait parameter (walking speed) in patients with knee OA after TKA. Twelve studies were included in the study, and it was concluded that TKA had a great influence on the walking speed of knee OA after 6–60 months. However, the study was published too earlier, only one gait parameter was discussed, and no subgroup analysis by various factors was carried out. Therefore, this study searched relevant studies in the databases before July 2024, and increased the number of included studies to 26. In addition, this study expanded the number of gait parameters to 11, and made several subgroup analyses by available data. The results showed that in patients with knee OA after TKA, there existed an increase in the max knee flexion, the cadence, the stride length, the walking speed, and the step length while a decrease in the double support time. Moreover, although no statistically significant differences, there was an increase trend in the knee ROM and the Max knee rotation at stance phase and a decrease trend in the Max knee extension, the step width and the stride time after TKA, which also reflected the improvement of walking function of patients with knee OA after operation in clinical practice. Subsequent studies may be needed to include more high-quality studies in analyzing these parameters for convincing results. Moreover, this study also made subgroup analysis by the follow-up and BMI. According to the subgroup analysis by the follow-up, compared with the follow-up of less than one year, the results of some gait parameters, such as max knee flexion, the cadence, the stride length and the walking speed, were more stable in the subgroup with the follow-up of more than one year. This phenomenon may suggest that we should follow up and evaluate gait parameters for at least one year in clinic. As for BMI, according to the subgroup analysis, we can't find the clear role of this factor in gait parameters, but several studies [38, 58] thought that high BMI may affect the running track of markers, thus showing some artifacts on the skin, which may affect the results of instrument detection. Therefore, the influence of BMI on gait parameters is worthy of continuous attention in the future.

In addition to the above factors, there were still several factor, including prosthesis type and infrapatellar fat pad (IFP) removal, affecting the gait parameters. The designs of commercially available prosthetic knee units are generally biomimetic in nature, and their functions are fundamentally similar. At a minimum, the prosthetic knee must provide stability during stance phase to ensure that the user is safely supported on their prosthesis, and it must flex during swing phase to shorten the prosthesis and allow the user to advance the limb. However, prosthesis users may not be able to fully or accurately articulate what they perceive when they stand and walk, making it difficult for the prosthetist to make all of the necessary adjustments. Augmenting the human body with a prosthesis markedly affects the individual's mode of travel [59]. The infrapatellar fat pad (IFP) is an adipose tissue present in the knee that lies between the patella, femur, meniscus and tibia, filling the space between these structures. Since that IFP and the adjacent synovial membrane may be considered a morpho-functional unit, playing a cushioning role in the knee and providing to distribute and to dampen the mechanical action during joint movement [60], there is still an active debate if IFP should be totally, partially, or not excised during TKR and which might be the consequences of these different approaches on postoperative pain [61].

It is necessary to consider the limitations of the present meta-analysis while interpreting the results. First, potential language bias might exist because only articles published in English were included in this literature. Second, this study did not explore the effect of different types of prosthesis using in TKA on gait parameters, which may lead to potential bias. Thirdly, the number of studies included is limited. The discussion on gait parameters before and after TKA is of great clinical significance, but the number of studies that can be included is very limited, which may be difficult to discuss more parameters such as rotation moment, and get convincing results. Fortunately, no publication bias existed in all results and sensitivity analysis showed that the pooled effect size results were robust.

Conclusion

In summary, the study found that, in patients with knee OA, total knee arthroplasty (TKA) may have great effects on improving gait parameters. If there are more high-quality studies in the future, we should make a more comprehensive evaluation of walking function by gait analysis together with other evaluation systems such as muscle strength and proprioception measurement.

Abbreviations

OA	Osteoarthritis
TKA	Total Knee Arthroplasty
ROM	Range Of Motion

Supplementary Information

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Supplementary Material 1: Supplementary Figure 1: Subgroup analysis of Max knee flexion. (A) BMI; (B) Follow up.

Supplementary Material 2: Supplementary Figure 2: Subgroup analysis of stride length. (A) BMI; (B) Follow up.

Supplementary Material 3: Supplementary Figure 3: Subgroup analysis of walking speed. (A) BMI; (B) Follow up.

Supplementary Material 4: Supplementary Figure 4: Subgroup analysis of step length. (A) BMI; (B) Follow up.

Supplementary Material 5: Supplementary Figure 5: The funnel plot for gait parameters. (A) Double support time; (B) Max knee extension; (C) Max knee flexion; (D) Knee ROM; (E) Max knee rotation at stance phase; (F) Cadence; (G) Step length; (H) Step time; (I) Step width; (J) Stride length; K) Stride time; L) walking speed.

Supplementary Material 6: Supplementary Figure 6: Sensitivity analysis for gait parameters. (A) Double support time; (B) Max knee extension; (C) Max knee flexion; (D) Knee ROM; (E) Max knee rotation at stance phase; (F) Cadence; (G) Step length; (H) Step time; (I) Step width; (J) Stride length; K) Stride time; L) walking speed.

Supplementary Material 7: Supplementary Table 1: Search strategy.

Supplementary Material 8: Supplementary Table 2: Publication bias and heterogeneity of summarized gait parameters.

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Author contributions
(I) Conception and design: Xinfeng Yu. (II) Administrative support: Rujie Zhuang. (III) Collection and assembly of data: Xinfeng Yu, Peng Jin. (IV) Data analysis and interpretation: Xinfeng Yu. (V) Manuscript writing: All authors. (VI) Final approval of manuscript: All authors.

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Data availability
All data generated or analysed during this study are included in this published article.

Declarations

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