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CLINICAL ARTICLE

Comparison of Single-Radius with Multiple-Radius Femur in Total Knee Arthroplasty: A Meta-Analysis of Prospective Randomized Controlled Trials

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Abstract

Background: Whether there was clinical superiority for the single-radius prosthesis over the multi-radius prothesis in total knee arthroplasty (TKA) still remains to be clarified. We updated a meta-analysis including prospective randomized controlled trials (RCTs) to compare the clinical prognosis of patients receiving single-radius TKA (SR-TKA) or multi-radius TKA (MR-TKA).

Methods: We searched the databases of PubMed, Web of Science, EMBASE, Cochrane Library, MEDLINE for eligible RCTs. Two reviewers evaluated the study quality according to the Risk of Bias tool of the Cochrane Library and extracted the data in studies individually. The extracted data included the baseline data and clinical outcome. The baseline data include the author's name, country, and year of included studies, the name of knee prosthesis used in studies, sample size, follow-up time, and BMI of patients. The clinical data comprised primary indicators including postoperative knee range of motion (ROM), sit-to-stand rest, severe postoperative scorings, such as visual analog scale (VAS), American Knee Society knee score (AKS), Oxford knee scoring (OKS), and SF-36 Quality of Life Scale, as well as various secondary indicators of complications including anterior knee pain, postoperative infection, aseptic prosthesis loosening, and prosthesis revision. The data analysis was performed using Review Manager 5.3 software and STATA 12.0. The sensitivity analysis was performed using STATA 12.0.

Results: A total of 13 RCTs, along with 1720 patients and 1726 knees, were finally included in our present meta-analysis. We found that patients in SR-TKA group performed better in the sit-to-stand test (OR $= 1.89$, 95% CI: 1.05–3.41, $p = 0.03$) and satisfaction evaluation (OR $= 3.27$, 95% CI: 1.42–7.53, $p = 0.005$), which were only evaluated in two included RCTs. While no significant difference was found between SR-TKA and MR-TKA groups in terms of postoperative ROM, VAS scoring, AKS scoring, SF-36 scoring, OKS scoring, and various complications including anterior knee pain, postoperative infection, aseptic prosthesis loosening, and prosthesis revision.

Conclusion: In conclusion, our present meta-analysis indicated that SR implants were noninferior to MR implants in TKA, and SR implants could be an alternative choice over MR implants, since patients after SR-TKA felt more satisfied and performed better in the sit-to-stand test, with no significant difference in complications between SR-TKA and MR-TKA groups. While more relevant clinical trials with long-term follow-up time and specific tests evaluating the function of knee extension mechanism should be carried out to further investigate the clinical performance of SR implants.

Key words: clinical outcomes; meta-analysis; prospective randomized controlled trials; single radius; total knee arthroplasty

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Introduction

Total knee arthroplasty (TKA) has been an effective surgery to relieve pain and restore the knee function of patients with advanced knee osteoarthritis and rheumatic arthritis1, since many clinical trials have demonstrated the excellent performance of different knee prostheses in terms of long-term survival[2]. However, unlike total hip arthroplasty (THA), the patient satisfactory rate for TKA was only 80%, despite its good long-term survival[3–6].

Some researchers ascribed the lower satisfaction of TKA, compared with THA, to the difficulty and complexity of elucidating the natural knee kinematics[7–9]. The knee joint is a complex hinge joint and could achieve various degrees of flexion, extension, abduction, adduction, intorsion, and extorsion in sagittal, coronal, or axial plane, respectively[10]. As such, there were many controversies about designing the optimized knee prosthesis to maximize the recovery of the natural knee movement. Among these debates, whether the tibia rotates around the femur in a single or multiple radius (SR or MR) still remains a major problem yet clarified[11,12].

Over a long time, the TKA using MR prosthesis (MR-TKA) was considered as a good choice to treat osteoarthritis. In recent years, however, some postoperative complications like instability of moderate flexion and weak quadriceps have been reported to cause patients dissatisfaction after MR-TKA[13,14]. Then the TKA using a SR prosthesis (SR-TKA), possessing a single-radius femoral component, was introduced in the expectation to overcome the disadvantages of MR-TKA. The single-radius design theoretically could avoid inconsistent movement of femoral component and extend the moment arm of extension mechanism when the knee was moderately flexed[15–17]. Despite the theoretical advantages of single-radius femoral component, many clinical studies comparing the clinical outcome of SR-TKA and MR-TKA have come to contradictory conclusions[18–23]. Meanwhile, Liu *et al.*[24] performed a comprehensive meta-analysis to compare SR-TKA and MR-TKA, reaching the conclusion that no clinical superiority for SR-TKA over MR-TKA was found, with lower knee range of motion in the SR-TKA group. However, the inclusion of some retrospective studies limits its reliability. In addition, many RCTs have been published from then on, among which the controversy still persists[20–23,25,26]. Therefore, it is strongly necessary to update this meta-analysis only including prospective randomized controlled trials to determine whether there were clinical advantages to SR-TKA over MR-TKA.

Herein, we update such a meta-analysis to comprehensively compare the clinical outcome of SR-TKA and MR-TKA in terms of various clinical scorings, postoperative function recovery, and complications.

Materials and Methods

Literature Retrieval

We performed a comprehensive search in the databases of MEDLINE, EMBASE, PubMed, Web of Science, the Cochrane library, as well as the clinicaltrial.gov. The retrieval formula in databases according to Boolean algorithm was "((((((single radius [MeSH Terms]) OR (multi radius [MeSH Terms])) OR (Scorpion [MeSH Terms])) OR (Scorpion NRG [MeSH Terms])) OR (Triathlon [MeSH Terms])) AND ((total knee arthroplasty [MeSH Terms]) OR (total knee replacement [MeSH Terms]))) AND (randomized controlled trials [MeSH Terms])", with retrieval time up to June 2019.

Literature Screening Criteria

After preliminary retrieval in various databases, we screened the eligible prospective randomized controlled studies according to the predetermined inclusion and exclusion criteria. The inclusion criteria included: (i) patients ≥18 years old with degenerative or other non-infection arthritis requiring TKA; (ii) participants who underwent SR-TKR or MR-TKA; (iii) comparison was performed between patients receiving SR-TKR and patients receiving MR-TKA; (iv) clinical outcomes reported in included studies comprising at least one of the following items: postoperative knee range of motion, various knee scoring, SF-36 scoring, sit-to-stand test, and postoperative complications including anterior knee pain, infection, aseptic prosthesis loosening, and knee prosthesis revision; (v) RCTs with a minimum follow-up over 1 year.

The exclusion criteria included: (i) retrospective studies, reviews, case reports, conference abstracts, and editorials; (ii) RCTs without eligible data availability; (iii) studies reporting a loss of more than 20% follow-up; (iv) non-English publications.

Literature Screening Process

The above literature retrieval and screening process was carried out individually by two authors. The two reviewers independently performed the whole screening and inclusion process. The combination of Endnote and manual screening was carried out to remove repetitive literature. Whether to include a study depends on the author carefully reading the full text and judging whether it meets the inclusion criteria. The controversy was addressed by discussion to reach consensus.

Study Quality Evaluation

Two individuals evaluated the quality of included studies independently, utilizing the Risk of Bias tool of the Cochrane Library[27], which was achieved by the software Review Manager. The study evaluation tool included seven parts and each item could be scored as high, unclear, or low risk according to the literature's content. Identically, if any disagreement occurs, we performed a conference to reach a consensus.

Data Extraction

The baseline data and clinical outcomes of patients was extracted from the included studies. The baseline data comprised the author's name, country, and year of included studies, the name of knee prosthesis used in studies, sample size, fellow-up time, and BMI of patients who were not lost to follow-up. The clinical outcome comprised primary indicators including postoperative knee range of motion (ROM), sit-to-stand test, satisfaction evaluation, severe postoperative scorings, such as visual analog scale (VAS), American Knee Society score (AKS), Oxford knee scoring (OKS), and SF-36 Quality of Life scale, as well as various secondary indicators of complications including anterior knee pain, postoperative infection, aseptic prosthesis loosening, and prosthesis revision.

Primary Indicators

Range of Motion (ROM) Measurement and Sit-To-Stand Test

When evaluating the ROM of the repaired knee, patients were in a supine position and a manual goniometer with range of 0°–360° was used to measure the passive maximum ROM of the knee. For the sit-to-stand test, patients firstly sit down in a chair, with the knee flexed at 90°. Then the patients were asked to stand up from the chair independently without any external force. The success rate of the sit-to-stand test was calculated according to whether patients could complete the test.

Satisfaction Evaluation

There were two studies reporting the satisfaction evaluation of patients after TKA, with the four-point or five-point Likert scale used for satisfaction evaluation. Each patient would report an attitude for their TKA, including very satisfied, satisfied, neutral, dissatisfied, and very dissatisfied. Then each patient could be divided into the satisfied group (very satisfied or satisfied) or dissatisfied group (the other answers).

American Knee Society Score (AKS) and Oxford Knee Scoring (OKS) Scoring

The AKS scoring has been a classical score system for evaluating the clinical efficiency of TKA, which was comprised of

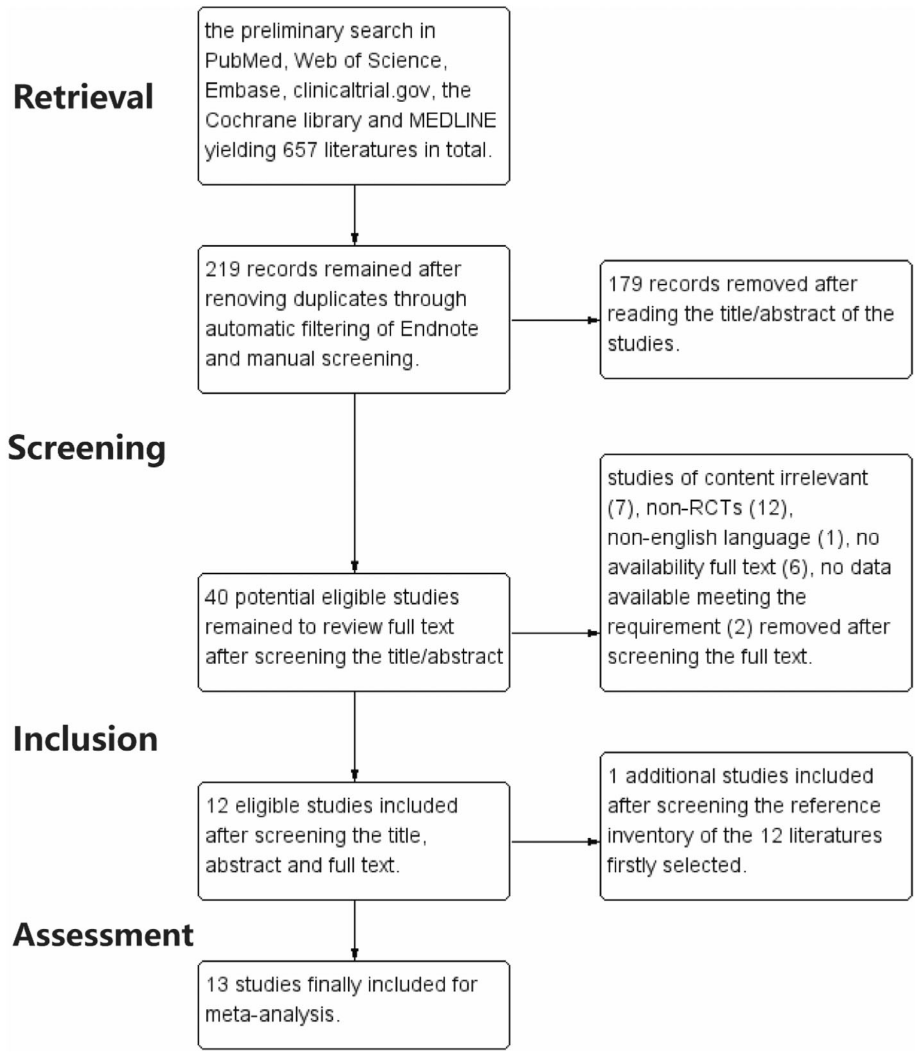

Fig. 1 The flow gram of study screening process, with 219 studies yielded after preliminary searching in various databases and 13 prospective randomized controlled studies finally included after reading abstract or full text

TABLE 1 Baseline data of included studies

			Knee prosthesis					Sample	
Included studies	Year	Country	SR-TKA	MR-TKA	Follow-up (year)	Mean age	BMI	SR-TKA	MR-TKA
Hall[18]	2008	USA	Scorpio, Stryker	PFC, DePuy	1	71.1	UC	50	50
Schmitt[28]	2011	Germany	Scorpio, Stryker	NexGen, Zimmer	1	69.4	31.5	30	30
Molt[29]	2012	Sweden	Triathlon, Stryker	Duracon, Stryker	2	67.5	28.8	30	30
Tamaki[a30]	2013	Japan	NRG, Stryker	Legacy-flex	1	74	UC	7(10)	7(10)
Jo[19]	2014	South Korea	Scorpio, Stryker	NexGen, Zimmer	3	66.9	26.9	50	50
Hamilton[31]	2015	England	Triathlon, Stryker	Kinemax, Stryker	3	68.3	UC	100	83
Kim[20]	2015	South Korea	Triathlon, Stryker	PFC, DePuy	1	67.2	27.3	55	54
Larsen[32]	2015	USA	Triathlon, Stryker	Biomet, Zimmer	1	71.3	29.6	16	16
Hinarejos[21]	2016	Spain	Triathlon, Stryker	Genutech, Surgival	5	72.2	31.3	250	224
Collados-Maestre[22]	2017	Spain	Trekking, Samo	Multigen, Lima	5	71.2	31	118	119
Wellman[23]	2017	USA	Triathlon, Stryker	NexGen, Zimmer	1	62.6	30.6	20	20
Lee[25]	2018	Singapore	Scorpio NRG, Stryker	NexGen, Zimmer	2	66	28	103	103
Mushtaq[26]	2018	USA	Scorpio, Stryker	Biomet, Zimmer	1	72.4	UC	51	54

[a] Patients receiving bilateral TKA using high flexion knee protheses or standard knee protheses; SR-TKA: single-radius total knee arthroplasty; MR-TKA: multi-radius total arthroplasty; UC: unclear; BMI: body mass index.

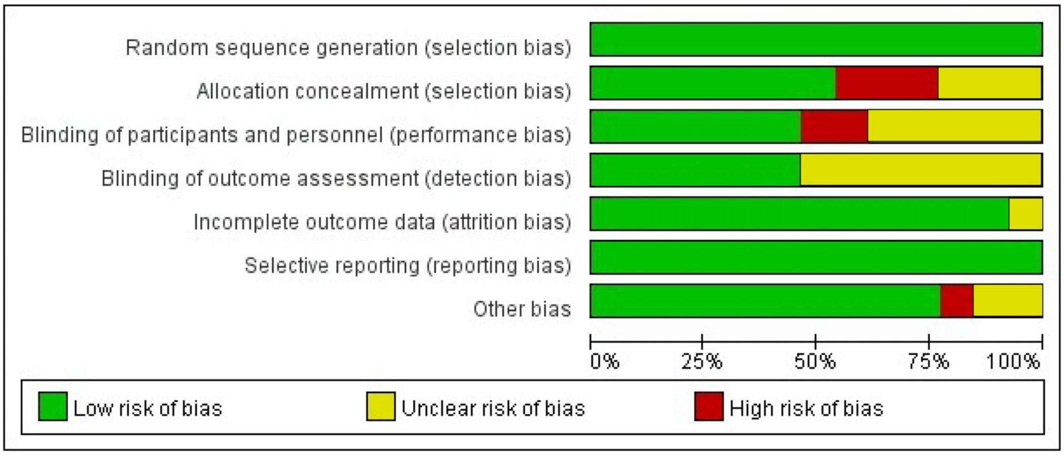

Fig. 2 Quality evaluation summary of included RCTs utilizing the Risk of Bias tool of the Cochrane Library for RCTs: judgments review of authors about each risk of bias item presented as percentages across all included studies

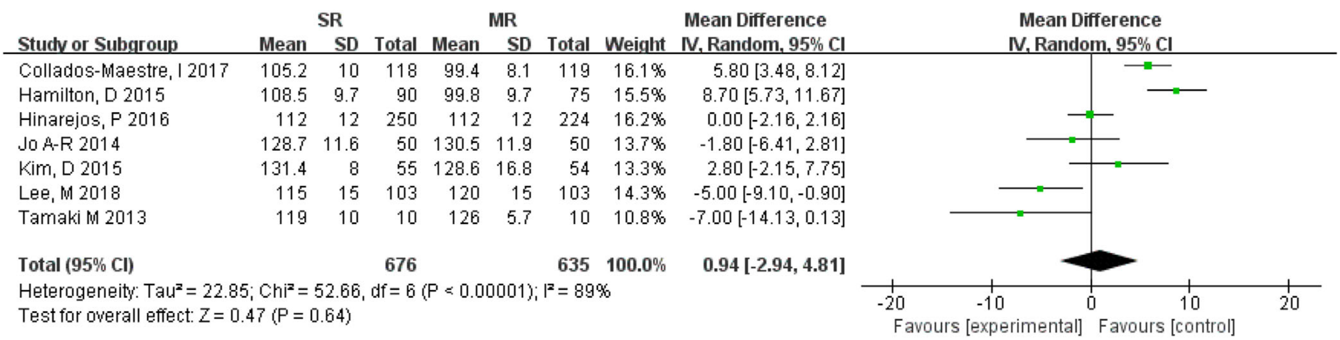

Fig. 3 The forest plot of postoperative knee ROM showing no significant difference between SR-TKA and MR-TKA. (SR-TKA: total knee arthroplasty using single radius prosthesis; MR-TKA: total knee arthroplasty using multi radius prosthesis.)

knee score and function score. The knee score mainly comprised the evaluation of pain, stability, and ROM of the repaired knee, and patient showing no pain, well-aligned knee prosthesis without mediolateral or anteroposterior instability, and more than 125°of ROM would get a maximum of 100 points. The function score evaluated the patient's ability to walk and climb stairs, with a maximum of 100 points representing unlimited walking distance and normal stair climbing ability. The OKS is a special score for patients after TKA, with 12-item questionnaire specifically designed and developed to assess function and pain of the repaired knee. The OKS score ranged from 0 to 48, and higher score represents better function and less pain of the repaired knee.

Visual Analog Scale (VAS) Scoring and SF-36 Quality of Life Scale

The VAS scoring was a measurement tool to quantify the subjective pain feeling of patients. The VAS score ranged from 0 to 10 points, with 0 representing no pain and 10 representing excruciating pain. The SF-36 score is a multifactor life quality score, which comprised the physical score part and the mental score part. The mental score was used for evaluating the mental status and social function of patients, while the physical score mainly evaluated the function and pain condition of the repaired knee.

Secondary Indicators

The secondary indicators including several perioperative complications that were reported in the included studies, such as anterior knee pain, postoperative infection, aseptic prosthesis loosening, and prosthesis revision.

Statistical Analysis

The extracted data was pooled and analyzed through Review Manager 5.3 software (Cochrane Collaboration, UK) and STATA (Computer Resource Center, USA). The sensitivity analysis was performed through STATA (Computer Resource Center, USA) when significant heterogeneity was detected. The continuous or dichotomous data were compared between two groups using the mean difference and odds ratios (ORs), respectively, along with the 95% confidence interval (CI). The difference was considered as statistical significance when $p < 0.05$ occurred. We utilized the random-effect or fixed-effect model to analyze the pooled results, respectively, when significant heterogeneity ($p < 0.10$; $I^2 > 50\%$) appeared or not. The sensitivity analysis was performed to evaluate the reliability of the pooled results through removing some studies from analyzed studies in each analysis.

Results

Literature Screening Results

As shown in Figure 1, there were 219 studies yielded after preliminary searching in various databases and removing duplicates. After carefully reading the title and abstract, 179 studies were excluded, with 40 potential eligible studies remained to review. After screening the full text of 40 potential qualified studies and the reference lists, we finally included 13 prospective randomized controlled studies that compared the clinical outcome between SR-TKA and MR-TKA.

Study Characteristics

The baseline data of included studies was summarized in Table 1. A total of 13 RCTs[7,17,18,20,23,26–28,33,35,42,44,45] along

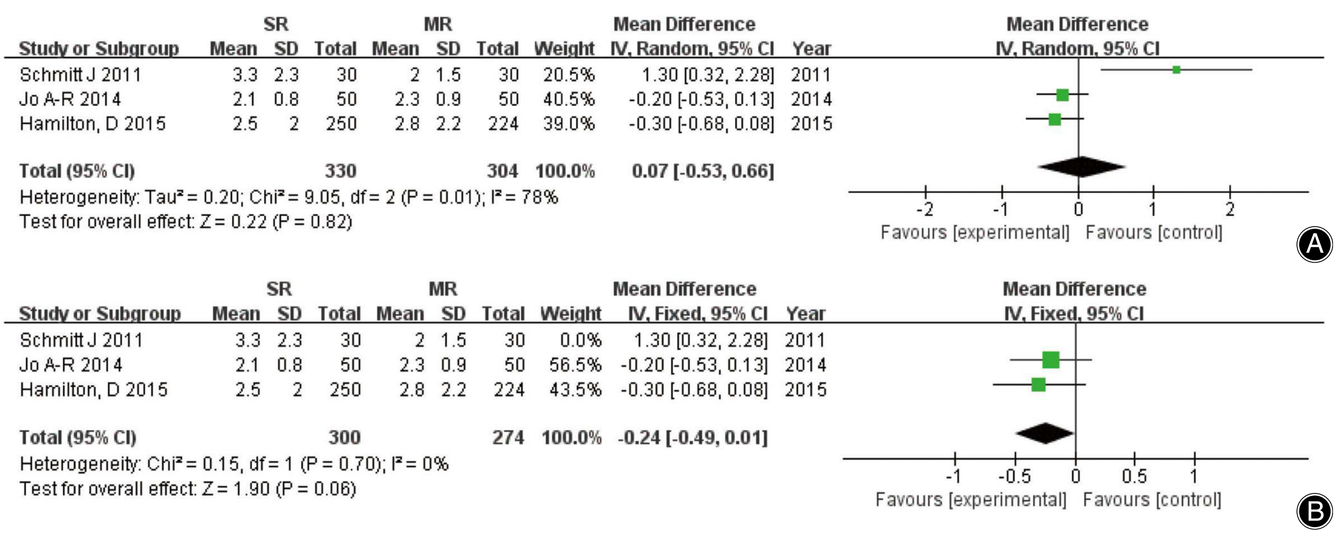

Fig. 4 (A). The forest plot of VAS scoring showing no significant difference between SR-TKA and MR-TKA. (B). The forest plot of VAS scoring after removing one study showing no significant difference between SR-TKA and MR-TKA

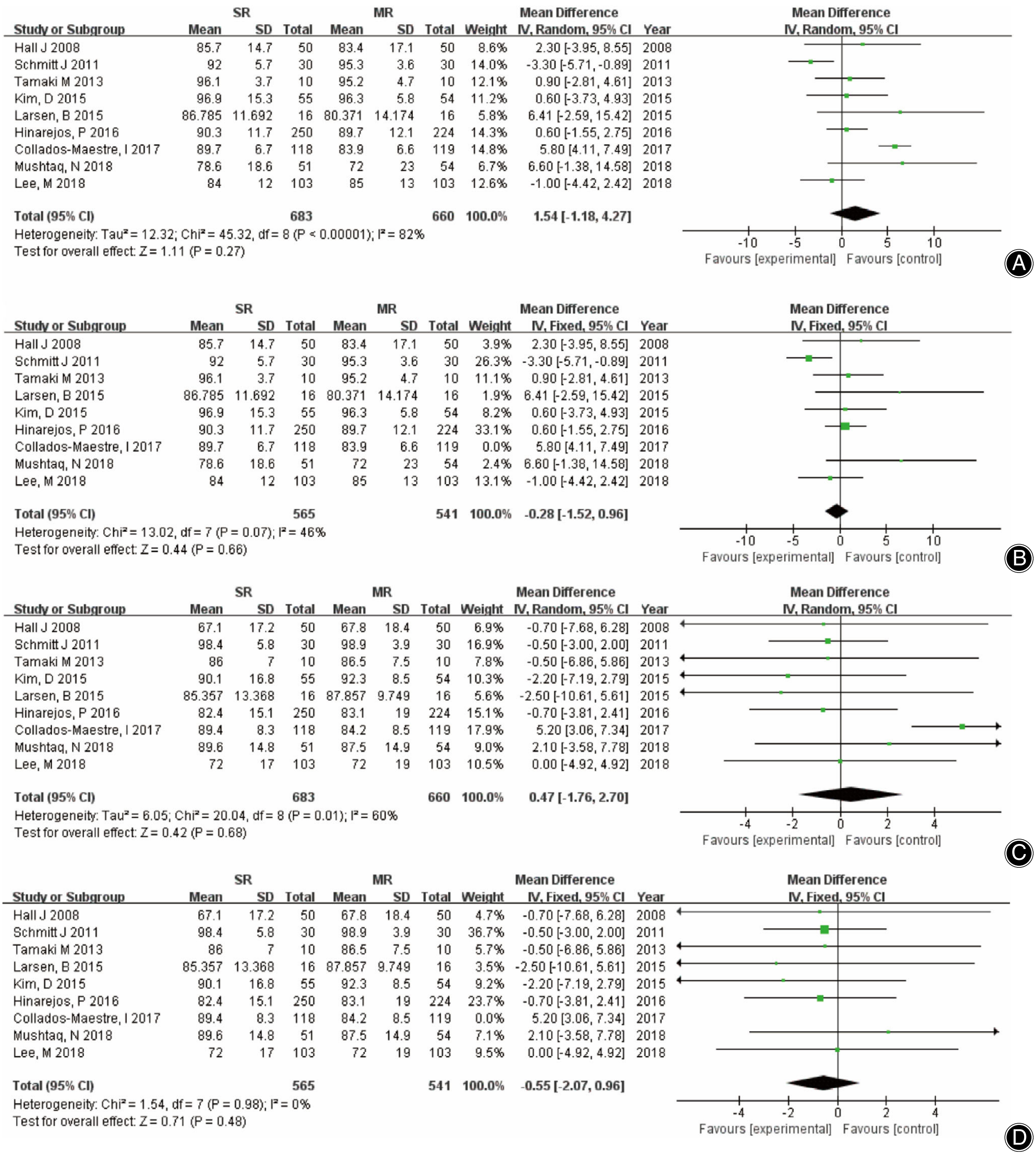

Fig. 5 The pooled results of different parts for AKS scoring: (A) The forest plot of postoperative knee society scoring of AKS and the relative forest plot after removing one study (B) showing no significant difference between SR-TKA and MR-TKA; (C) The forest plot of postoperative knee function scoring of AKS and the relative forest plot after removing one study (D) showing no significant difference between SR-TKA and MR-TKA

with 1720 patients and 1726 knees were included for meta-analysis to compare the clinical outcome after SR-TKA or MR-TKA. There were 880 patients included in the SR-TKA group and 840 patients in the MR-TKA group. The minimum follow-up time of included patients was over 1 year, with the mean age of 69.7 years for all included patients.

All patients included in these studies suffered from degenerative knee arthritis. The SR knee prosthesis used in included studies comprised Scorpion, Scorpion NRG, Triathlon, and Trekking knee system. And the MR knee prosthesis used in included studies varied in prosthetic brands, such as Stryker, Zimmer, and DePuy. The evaluation of study quality was summarized in Figure 2. All included studies were prospective randomized controlled trials, while some showed high risks in allocation bias and other bias due to the lack of allocation concealment or the partial loss of patient follow-up.

Meta-analysis of Primary Clinical Outcomes

Range of Motion (ROM) Measurement

As shown in Figure 3, there were seven studies[19–22,25,30,31] reporting postoperative ROM, with significant heterogeneity occurring among compared studies (p<0.01, I^2 = 89%). The sensitivity analysis (Figure S1) indicated that the pooled results was stable. Therefore, we utilized random-effect model to analyze the results, showing no significant difference between SR-TKA and MR-TKA (MD = 0.94, 95% CI: − 2.94, − 4.81, p = 0.64).

Visual Analog Scale (VAS) Scoring

The VAS scoring was utilized in three studies[19,28,31] to evaluate the postoperative knee pain. Due to the significant heterogeneity (p = 0.01, I^2 = 78%), presented in Figure 4A, the sensitivity analysis (Figure S2) was performed and indicated that the heterogeneity came from one study[28]. As such, we performed analysis again after removing the study, and the pooled results (Figure 4B) revealed no significant difference between the two groups (MD = − 0.24, 95% CI: − 0.49, 0.01, p = 0.06).

American Knee Society Score (AKS) Scoring

There were nine studies[18,20–22,25,26,28,30,32] reporting the AKS-society scoring along with SD. As presented in Figure 5A, due to the significant heterogeneity (p<0.01, I^2 = 82%), the sensitivity analysis (Figure S3) was performed and indicated that the heterogeneity came from one study[22]. Therefore, we performed analysis again after removing the study, and the pooled results (Figure 5B) revealed no significant difference between the two groups (MD = − 0.28, 95% CI: − 1.52, 0.96, p = 0.66).

The AKS-function scoring along with SD was available in nine studies[18,20–22,25,26,28,30,32]. Because of the existence of significant heterogeneity (p = 0.01, I^2 = 60%, Figure 5C), the sensitivity analysis (Figure S4) was performed and indicated that the heterogeneity come from one study[22]. Therefore, we performed analysis again after removing the study, and the pooled results (Figure 5D) revealed no significant difference between the two groups (MD = − 0.55, 95% CI: − 2.07, 0.96, p = 0.48).

Oxford Knee Scoring (OKS)

The OKS along with SD was available in three studies[25,26,31]. As shown in Figure 6, with slight heterogeneity identified (p = 0.13, I^2 = 51%), the random-effect model was chosen to perform the meta-analysis of the pooled results. No statistical significance was detected between SR-TKA and MR-TKA (MD = 1.13, 95% CI: − 0.77, − 3.03, p = 0.24).

SF-36 Scoring

As shown in Figure 7A, there were three studies[21,22,25] reporting the SF-36 mental scoring with SD. Due to the lack of obvious heterogeneity (p = 0.36, I^2 = 3%), we used the fixed-effect model to analyze the pooled results, revealing no statistical difference between the two groups (MD = 0.45, 95% CI: − 0.84, − 1.74, p = 0.50). Identically, the SF-36 physical scoring along with SD was available in three studies[21,22,25], and the pooled results indicated no significant heterogeneity (p = 0.58, I^2 = 0%) between the compared studies. As presented in Figure 7B, there was no significant difference between SR-TKA and MR-TKA in terms of SF-36 physical scoring (MD = 0.86, 95% CI: − 0.29, − 2.01, p = 0.14).

Sit-To-Stand Test and Satisfaction Evaluation

As shown in Figure 8A, the sit-to-stand test was only carried out in two studies[18,22]. Because no obvious heterogeneity was detected (p = 0.74, I^2 = 0%), we applied the fixed-effect model to analyze the pooled results, which indicated significant difference between SR-TKA and MR-TKA (OR = 1.89, 95% CI: 1.05, − 3.41, p = 0.03). As for patient satisfaction evaluations, there were two studies comparing the postoperative satisfaction rate of patients receiving SR-TKA or MR-TKA[22,31]. As shown in Figure 8B, because no evidence of significant heterogeneity was detected (p = 0.50, I^2 = 0%), we utilized the fixed-effect model to analyze the pooled results, revealing significant

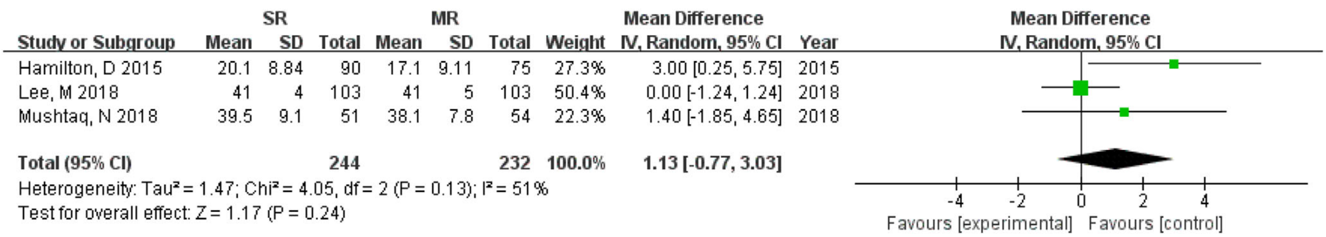

Fig. 6 The forest plot of OKS scoring showing no significant difference between SR-TKA and MR-TKA

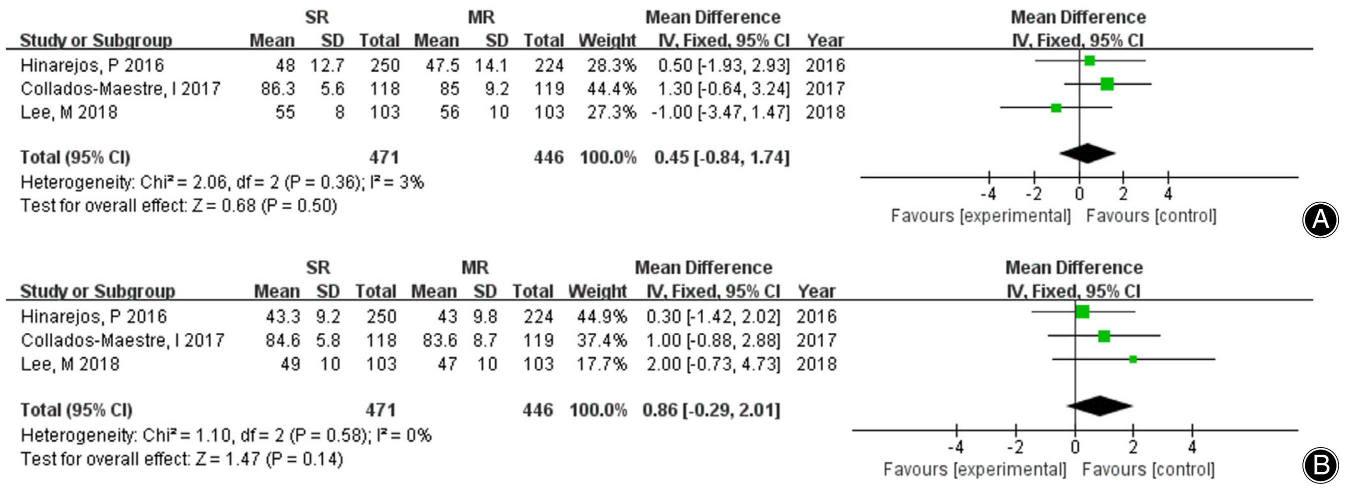

Fig. 7 The pooled results of different parts for SF-36 scoring: (A) The forest plot of postoperative SF-36 mental scoring showing no significant difference between SR-TKA and MR-TKA; (B) The forest plot of postoperative SF-36 physical scoring showing no significant difference between SR-TKA and MR-TKA

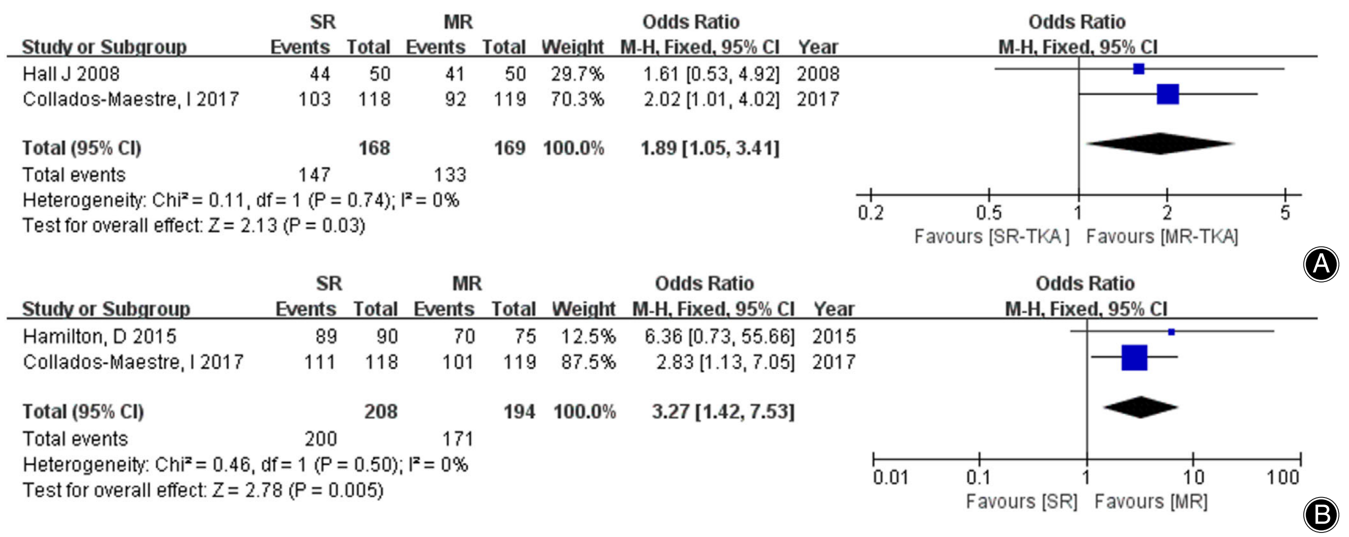

Fig. 8 The pooled results of the sit-to-stand test and satisfaction evaluation for comprehensively determining the function of quadriceps: (A) The forest plot of postoperative sit-to-stand test showing significant difference between SR-TKA and MR-TKA; (B) The forest plot of postoperative patient satisfaction rate showing significant difference between SR-TKA and MR-TKA

TABLE 2 The results of meta-analysis for various complications

	SR-TKA		MR-TKA					
complications	Events	Total	Events	Total	Heterogeneity	Analysis model	ORs (95% CI)	*p*
Infection[22,28,29,31]	4	178	5	179	$I^2 = 0\%, p = 0.95$	Fixed-effect model	0.75 (0.20–2.83)	0.67
Anterior knee pain[18,22,25]	10	271	10	272	$I^2 = 45\%, p = 0.16$	Fixed-effect model	1.0 (0.42–2.41)	1.0
Aseptic loosening[22,25,28]	4	251	3	252	$I^2 = 0\%, p = 0.83$	Fixed-effect model	1.30 (0.32–5.32)	0.72
Revision[22,25,29,31]	7	336	5	322	$I^2 = 0\%, p = 0.51$	Fixed-effect model	1.31 (0.845–3.80)	0.62

Abbreviations: MR-TKA: multi-radius total knee arthroplasty; SR-TKA: single-radius total knee arthroplasty.

difference in terms of patient satisfaction rate between SR-TKA and MR-TKA groups (OR = 3.27, 95% CI: 1.42, − 7.53, $p = 0.005$). The sit-to-stand test and satisfaction rate evaluation indicated that patients in the SR-TKA group showed higher rate in completing the function test and feeling satisfied after TKA, as compared with the patients in the MR-TKA group.

Meta-Analysis of Secondary Clinical Outcomes

Postoperative Complications

The postoperative complications after SR-TKA or MR-TKA was summarized in Table 2. Due to the limited information of complications reported in included studies, we only analyzed postoperative infection, anterior knee pain, and aseptic prosthesis loosening between two groups, with the pooled results revealing no significant difference between SR-TKA and MR-TKA.

Discussion

The present updated meta-analysis comprehensively compared the clinical outcome comprising postoperative ROM, VAS scoring, AKS scoring, OKS scoring, SF-36 scoring, sit-to-stand test, and complications between SR-TKA and MR-TKA groups. The pooled results revealed no significant difference between the two groups in various functional scorings and complications, except for the sit-to-stand test and satisfaction evaluation, of which statistical significance was detected between the two groups.

Since TKA was introduced to treat terminal osteoarthritis and rheumatic arthritis, it has been identified as one of the most successful surgeries, with a 10-year prosthetic survival rate of more than 95%[33]. However, good long-term survival of knee prosthesis doesn't necessarily mean that patient is equally satisfied with the operations. According to some clinical research findings, there were always 15%–20% of patients who felt dissatisfied or stilted with their replaced knee joints[7,34]. There were many factors affecting patient satisfaction with TKA, such as sports demand, psychological factors, surgical skills, postoperative rehabilitation, and prosthesis design[6,8]. Among these factors, the implant design plays a critical role in affecting the prognosis and patient feeling after TKA[35]. In order to design the more bionic knee implants, some researchers and manufacturers have paid a lot of attention to exploring the natural mechanism of knee motion.

In 1971, the J-curve theory related to the knee motion mechanism was proposed by Burstein, who thought the radius in which the tibia rotated around the femur gradually decreased as the knee moved from extension to flexion[36], and this theory was subsequently translated into the MR design of knee implants. Since the first MR knee system was explored, the MR-TKA have long been applied as a primary knee arthroplasty operation for over 25 years. Nevertheless, some complications occurring after MR-TKA, such as midrange instability and unnatural feelings, raised doubts about the J-curve theory. Some researchers ascribed the complications to the slow recovery of extension mechanism[37,38]. Indeed, robust extension mechanism, especially for quadriceps, was essential to complete the daily motion of knees[39]. Meanwhile, rapid recovery of quadriceps after TKA could improve the postoperative clinical outcomes and patient satisfaction rate[15,40,41]. As such, it was crucial to enhance the strength of quadriceps and improve the function of extension mechanism when we performed TKA for patients. With this in mind, the first SR design of knee prosthesis named Scorpio was developed by Stryker[42]. The SR knee implants was characterized by the single curvature of femoral component, which could theoretically promote quadriceps recovery and extend the moment arm of quadriceps, thereby improving the knee motion function. In addition, the SR design could maintain the tension of collateral ligaments to avoid midrange instability.

Despite these theoretical advantages, the actual comparison of clinical outcomes between SR-TKA and MR-TKA were not always consistent with the expectation. In various clinical scorings, comprising KSS, SF-36, VAS, and OKS, no significant difference was detected in most of these studies[19–21,25,31,32], and neither did our present meta-analysis. However, it was worth noting that these function scorings were not sensitive enough to detect significant difference between SR-TKA and MR-TKA, since the theoretical advantages of SR knee prosthesis, including extended knee extension arm, midrange stability, and rapid quadriceps recovery, could not be embodied through these functional scorings[24,43]. Given the limitations of these scorings, some researchers tried to evaluate the postoperative performance and function of the knee extension mechanism[18,20,22,32]. Hamilton *et al*[31] reported that patients in SR-TKA group had better recovery of lower limb strength and began functional knee activities earlier, making the patients receiving SR-TKA more satisfied than patients in MR-TKA group. Similarly, Larsen *et al*[32] found that the knee forces of patients receiving MR-TKA was significantly lower than that in SR-TKA group. In contrast, Kim *et al*[20] found no significant difference between SR-TKA and MR-TKA groups in the rate or ratio of quadriceps recovery. Due to the differences of indicators and testing methods in various studies, we could not carry out a meta-analysis to compare the postoperative quadriceps strength between the two groups. Identically, we could not perform a meta-analysis to compare midrange instability between SR-TKA and MR-TKA, despite the contradictory conclusion in different studies[19,31,32,44]. However, the pooled results of sit-to-stand test and patient satisfaction in our present meta-analysis showed significant difference between two groups. In the sit-to-stand test, patients were required to get up from a chair without the help of hands or crutches, which could comprehensively reflect the functional status of knee extension mechanism[45]. And the satisfaction evaluation was performed to reflect the subjective feeling of patients, which combined with the sit-to-stand test could specifically determine whether the theoretical advantages of SR knee prosthesis could be translated into clinical value. Therefore, the pooled results of the sit-to-stand and satisfaction evaluation demonstrated the advantages of SR-TKA over MR-TKA to a certain degree. Besides, we found no significant difference in terms of postoperative ROM between the two groups. Liu *et al.*[24] reported that the postoperative ROM of patients in SR-TKA group was 2.47° less than that of MR-TKA group (95% CI: − 4.31 to − 0.64, $p = 0.46$), which was contradictory to the results of our present meta-analysis. However, it did not mean clinical significance of such a difference less than 5° in ROM[46]. Therefore, we believed that patients after SR-TKA could experience comparable knee ROM with patients after MR-TKA.

In general, the primary clinical outcomes indicating patients after SR-TKA felt more satisfied and performed better in the sit-to-stand test, with no significant difference in secondary indicators of complications between SR-TKA and MR-TKA groups. As such, we would like to recommend the SR knee prosthesis as a noninferior choice for patients required a TKA as compared with the MR knee prosthesis.

Study Strength and Limitations

The present meta-analysis incorporated all prospective randomized controlled trials in the literature with a large sample size of 1720 patients. In addition, we specifically analyzed the sit-to-stand test and satisfaction outcome to determine whether the theoretical advantages could be translated into clinical benefits. Nevertheless, there are deficiencies of our present meta-analysis which may affect the ability to draw and generalizable conclusions. Firstly, the language bias of the present meta-analysis was difficult to avoid since we only included RCTs published in English. Secondly, the longest fellow-up time of included studies was 5 years and the lack of long-term fellow-up data limited the confidence level of the present meta-analysis. Thirdly, the indication for SR implants and surgical technique were inconsistent, which could have caused significant heterogeneity when some clinical outcomes were analyzed. In addition, due to the significant heterogeneity of some pooled results, we performed sensitivity analysis for the pooled results of postoperative ROM (Figure S1), VAS scoring (Figure S2), AKS scoring (Figures S3 and S4), and OKS scoring (Figure S5), and re-analysis was performed to get more convincing pooled results. In general, more relevant clinical trials with long-term follow-up time and specific tests evaluating the function of knee extension mechanism should be carried out to further investigate the clinical performance of SR implants.

Conclusion

The present meta-analysis found patients in SR-TKA group felt more satisfied and performed better in the sit-to-stand test, as compared with patients in MR-TKA group. No statistical difference was detected in terms of knee ROM, various scorings, and complications between the two groups. Hence, based on this study we find that SR-TKA was noninferior to MR-TKA and may be a preferable choice for patients suffering advanced osteoarthritis and rheumatic arthritis.

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Author Contributions

Yihe Hu and Pengfei Lei conceived the original idea of this manuscript. Pengfei Lei, Zichao Jiang, and Ting Lei screened out eligible studies separately. Yihe Hu, Pengfei Lei, and Hu Qian discussed the controversial parts of literature screening and selected the studies finally included. Ting Lei, Zichao Jiang, and Pengfei Lei completed data analysis and finished the manuscript. David Backstein and Pengfei Lei revised the manuscript. All authors have read and approved the manuscript.

Conflict of Interest

The authors report no conflict of interest.

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