Int J Clin Exp Med 2019;12(8):9508-9521
www.ijcem.com /ISSN:1940-5901/IJCEM0094405

Review Article

Single radius versus multiple radius femoral prostheses in total knee arthroplasty: a meta-analysis

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Received March 26, 2019; Accepted June 10, 2019; Epub August 15, 2019; Published August 30, 2019

Abstract: Clinical studies comparing single radius (SR) and multiple radius (MR) femoral designs have provided controversial results. The current meta-analysis only included randomized controlled trials, aiming to provide high-quality evidence of clinical differences in both designs. The current study included 12 articles, reporting clinical outcomes of 1,204 knee replacements in 588 knees replaced with SR and 616 knees replaced with MR. Comparing SR with MR, the current study examined Knee Society Scores for the Knee (KSS-knee), KSS-function, knee injuries, Knee Osteoarthritis Scores (KOOS), Oxford Knee Scores (OKS), range of motion, flexion, extension, complications, and revision rates. SR knees with patellar resurfacing showed improved KSS-knee scores 1-year postoperatively (weighted mean difference [WMD]: 3.59, 95% confidence interval [CI]: 0.68 to 6.51, P = 0.02), while MR knees without patellar resurfacing also showed improved KSS-knee scores 1-year postoperatively (WMD: -2.31, 95% CI: 0.85 to 3.78, P = 0.002). WMD in the range of motion (ROM) (5.13°, 95% CI: 2.69° to 7.57°; P < 0.0001) was significantly in favor of SR. SR knees performed chair tests significantly better (odds ratio = 2.03; 95% CI: 1.13 to 3.64, P = 0.02) than MR knees. No significant differences were detected in other aspects. In conclusion, results of the current meta-analysis suggest that SR prostheses in total knee arthroplasty (TKA) result in improved ROM and enhanced extensor function.

Keywords: Total knee arthroplasty, single radius, multiple radius, meta-analysis

Introduction

Total knee arthroplasty (TKA) is a highly successful and cost-effective procedure for advanced osteoarthritis and rheumatoid arthritis [1-3]. Primary TKA has been shown to offer long-term survival rates > 95% [1-3]. However, there have been several complaints with this procedure, regarding anterior knee pain, instability, limited range of motion, and extensor insufficiency, probably related to the kinematics of knee prostheses [1-4]. In classical knee kinematics, the transient rotating center of femoral condyles moves downward and backward through flexion, while the radius of the condylar curvature diminishes [4]. Thus, the major femoral components of contemporary TKA are multi-radius (MR) in design.

In contrast, MR curves and changing centers of the posterior condyles are presented when observing from the coronal, sagittal, and transverse planes [5]. Hollister et al. [6] analyzed the natural knee. They found that the posterior condyles of the femur are curves with a single curvature radius, as observed in the plane perpendicular to the transepicondylar axis. Kinematic studies have confirmed that the cylindrical axis is coincident with the natural flexion-extension axis of the knee, passing through the origins of the anterior cruciate ligament and posterior cruciate ligament [5, 7]. Therefore, some implant designs have incorporated SR for the femoral component. SR prostheses might present the following mechanical advantages: (1) The SR configuration maintains the collateral ligaments in an isometric form during knee movement, thereby providing sustained stability. Conversely, prostheses with an MR design lead to mid-flexion instability and femoral paradoxical anterior movement, due to the laxity of the collateral ligaments and the modified condylar radius [8, 9]; (2) In SR, the femoral-tibial contact point is posterior. This improves the mechanical efficiency by providing a longer extensor moment arm and reducing pressure in the patellofemoral joint [10, 11].

However, clinical studies comparing SR and MR femoral designs have provided contradictory results [12-31]. Liu et al. [32] conducted a meta-analysis, aiming to detect differences in clinical outcomes between the SR and MR femoral design. It included several retrospective trials, weakening their conclusions. Thus, the present meta-analysis only included randomized controlled trials (RCTs), aiming to provide high-quality evidence concerning clinical differences in both designs, with respect to: (1) Clinical rating scores; (2) Mechanical properties in terms of range of motion (ROM) and extensor mechanisms; and (3) Complications and revisions.

Materials and methods

PubMed, Embase, Web of Science, and the Cochrane Central Register of Controlled Trials databases were searched for reports published from the inception to December 2017. The aim of the search was to identify RCTs that compared the effects of SR and MR TKAs. Free-text term strings were used as follows: (single radius OR multiple radius OR Triathlon OR Scorpio OR NRG) AND (total knee arthroplasty OR total knee replacement). Also, a search of the references for recent meta-analyses and reports of meetings was undertaken. No restrictions were placed on language. Eligible studies were selected by screening the titles and abstracts. If this was deemed insufficient, entire articles were reviewed.

Prospective RCTs involving primary TKA with the femoral component design in each group were included in this study.

Studies were excluded if they were non-randomized, duplicated studies, animal or cadaver studies, biomechanical studies, and reviews or correspondence.

Present authors (LMY, DZT), independently, assessed all titles and abstracts for eligibility. Full texts were obtained if at least one author judged the study as eligible. Disagreements were resolved by consensus. Following the flowchart of the Cochrane Handbook for Systematic Reviews of Interventions, the reviewers (MYC, LJX) assessed random sequence generation, allocation concealment, blinding of participants and personnel, blinded evaluation of the outcomes, completeness of the outcome data, selective reporting, and other biases. Each domain was scored as "no risk of bias", "high risk of bias", or "unclear".

Primary outcomes were clinical function assessment systems, including Knee Society Scores (KSS) and Knee Injury, Osteoarthritis Outcome Scores (KOOS), and Oxford Knee Scores (OKS). Secondary outcomes included range of knee motion, gait analysis, evaluation of extension mechanisms via chair tests, and all prosthesis-related complications.

The current study was performed in accordance with the Cochrane Handbook for Systematic Reviews of Interventions [33]. Review Manager (RevMan 5.3, The Cochrane Collaboration, Copenhagen, Denmark) was used to extract data for statistical analysis. Chi-square tests were used for heterogeneity testing if research objects, intervention measures, and methods of assessing outcomes were identical. A fixed-effects model was used for meta-analysis in the absence of heterogeneity ($I^2 < 50\%$). A random-effects model was used in the case of significant heterogeneity ($I^2 > 50\%$). Mantel-Haenszel tests (M-H) were used for enumeration data, while inverse variance (IV) was used for measurement data. A random-effects model was used for all data analysis because of the small study numbers. Weighted mean differences (WMD) were calculated for measurement data, while odds ratios (OR) were calculated for enumeration data. Moreover, 95% confidence intervals (CIs) were calculated for all meta-analyses ($P < 0.05$).

Results

A total of 468 articles were identified from searched databases. After the application of exclusion criteria, a total of 12 papers, in English, were included in this meta-analysis (**Figure 1**) [12-23]. **Table 1** provides the demographic data from all included RCTs. **Figure 2A**, **2B** indicate the quality of each study. A total of 1,194 patients with 1,204 knees were enrolled in this meta-analysis. Of these, 588 knees were

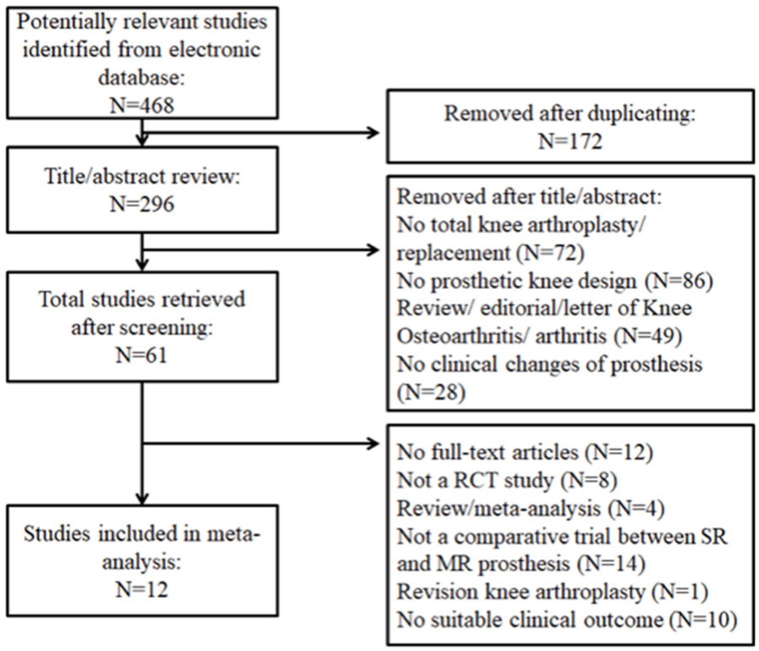

Figure 1. Flowchart outlining the process of this meta-analysis. SR, single radius; MR, multiple radius; RCT, randomized controlled trial. After the application of exclusion criteria, a total of 12 papers, all in English, were included in this meta-analysis.

replaced with SR prosthesis, while 616 were replaced with MR prosthesis.

KSS-knee

Nine studies reported KSS-knee scores as the clinical assessment (**Figure 3**). KSS-knee results were analyzed based on the follow-up period: (1) Three-month follow-up: WMD = -7.91; 95% CI = -16.57 to 0.75 (*P* = 0.07); (2) Results of 1-year follow-ups were categorized based on protheses types: Cruciate ligament retaining (CR) subgroup: WMD = 2.29, 95% CI = -4.21 to 8.79 (*P* = 0.49); Posterior stabilizing (PS) subgroup: WMD = 2.05, 95% CI = -1.89 to 5.99 (*P* = 0.31); Total WMD = 2.25, 95% CI = -0.99 to 5.50 (*P* =0.95); (3) One-year follow-up results were categorized based on whether patellar resurfacing was performed: Patellar resurfacing subgroup: WMD = 3.59, 95% CI = 0.68 to 6.51 (*P* = 0.02); No patellar resurfacing subgroup: WMD = -2.31, 95% CI = -3.78 to -0.85 (*P* = 0.002); Total WMD = 1.32, 95% CI = -1.84 to 4.48 (*P* = 0.41); and (4) Two-year-follow-ups: WMD = 2.41; 95% CI = -2.78 to 7.61 (*P* = 0.36). Statistically significant differences were detected between patellar resurfacing subgroups, displaying contradictory results. However, no significant differences were detected in other subgroups.

KSS-function

This outcome was assessed in 9 studies. Results, in accord with KSS-knees, were detected in KSS-function (**Figure 4**). In addition, KSS-function results were analyzed based on the follow-up period, protheses types, and whether patellar resurfacing was performed: (1) Three-month follow-up: WMD = -4.76; 95% CI = -10.41 to 0.90 (*P* = 0.10); (2) One-year follow-up, CR subgroup: WMD = 0.58, 95% CI = -6.59 to 7.75 (*P* = 0.87); PS subgroup: WMD = -0.48, 95% CI = -2.30 to 1.35 (*P* = 0.61); Total WMD = -0.01, 95% CI = -2.87 to 2.84 (*P* = 0.78); (3) One-year follow-up, patellar resurfacing subgroup: WMD = 0.58, 95% CI = -3.69 to 4.85 (*P* = 0.79); No patellar resurfacing subgroup: WMD = -1.88, 95% CI = -5.30 to 1.55 (*P* = 0.28); Total WMD = -0.30, 95% CI = -3.46 to 2.86 (*P* = 0.85); and (4) Two-year-follow-up: WMD = 2.41; 95% CI = -2.78 to 7.61 (*P* = 0.36). No significant differences were detected in either of the groups.

KOOS

This outcome assessment was available in 3 studies. The 1-year and 2-year results were assessed independently. Results of each timepoint were divided into 5 subgroups, based on categories of KOOS scores.

Two RCTs reported KOOS scores 1 year postoperatively (**Figure 5A**). No significant differences were detected: (1) Pain: WMD = -2.69; 95% CI = -11.64 to 6.26 (*P* = 0.56); (2) Symptoms: WMD = -2.13; 95% CI = -5.28 to 1.02 (*P* = 0.18); (3) Ability of daily life (ADL): WMD = -4.29; 95% CI = -17.76 to 9.18 (*P* = 0.53); (4) Sports: WMD = -5.83; 95% CI = -15.17 to 3.50 (*P* = 0.22); and (5) Quality of life (QOL): WMD = -6.28; 95% CI = -14.02 to 1.64 (*P* = 0.11).

Two RCTs reported KOOS scores 2-years postoperatively (**Figure 5B**). Marked differences

Table 1. Details of all studies included in the meta-analysis

Study	Design	Country of Origin	Number of Patients	Number of Knees	Brand of Prosthesis	SR	MR	Gender (M/F)		Average age (y)		Mean follow-up (mo)
								SR	MR	SR	MR	
Mushtaq et al. [12]	RCT	United Kingdom	105	105	Scorpio; AGC	51	54	n/s	n/s	n/s	n/s	12
Wellman et al. [13]	RCT	USA	40	40	Triathlon; NexGen	20	20	8/12	10/10	61.9	63.1	12
Collados-Maestre et al. [14]	RCT	Spain	237	237	Trekking; Multigen	118	119	37/81	35/84	71.9	70.6	68.4
Kim et al. [15]	RCT	South Korea	120	120	Triathlon; PFC Sigma	60	60	n/s	n/s	67.2	67.2	12
Larsen et al. [16]	RCT	USA	32	32	Triathlon; Vanguard	16	16	8/8	8/8	71.6	70.9	12
Hamilton et al. [17]	RCT	United Kingdom	212	212	Triathlon; Kinemax	108	104	46/62	35/69	69.3	68.8	36
Jo et al. [18]	RCT	South Korea	100	100	Scorpio; Nexgen	50	50	6/44	9/41	66.4	67.5	36.8
Menciere et al. [19]	RCT	France	84	88	Triathlon; PFC	45	43	17/28	17/26	65.5	65.4	19.5
Tamaki et al. [20]	RCT	Japan	14	20	Scorpio NRG; Legacy-flex	10	10	2/12	n/s	73	74.9	11.3
Molt et al. [21]	RCT	Sweden	60	60	Triathlon; Duracon	30	30	8/22	13/17	69	66	24
Schmitt et al. [22]	RCT	Germany	90	90	Scorpio; NexGen	30	60	8/22	20/40	69.2	69.9	36
Hall et al. [23]	RCT	USA	100	100	Scorpio; PFC	50	50	n/s	n/s	69.5	72.6	12

SR, single radius; MR, multiple radius; M, male; F, female; RCT, randomized controlled trial; n/s, not stated; mo, month.

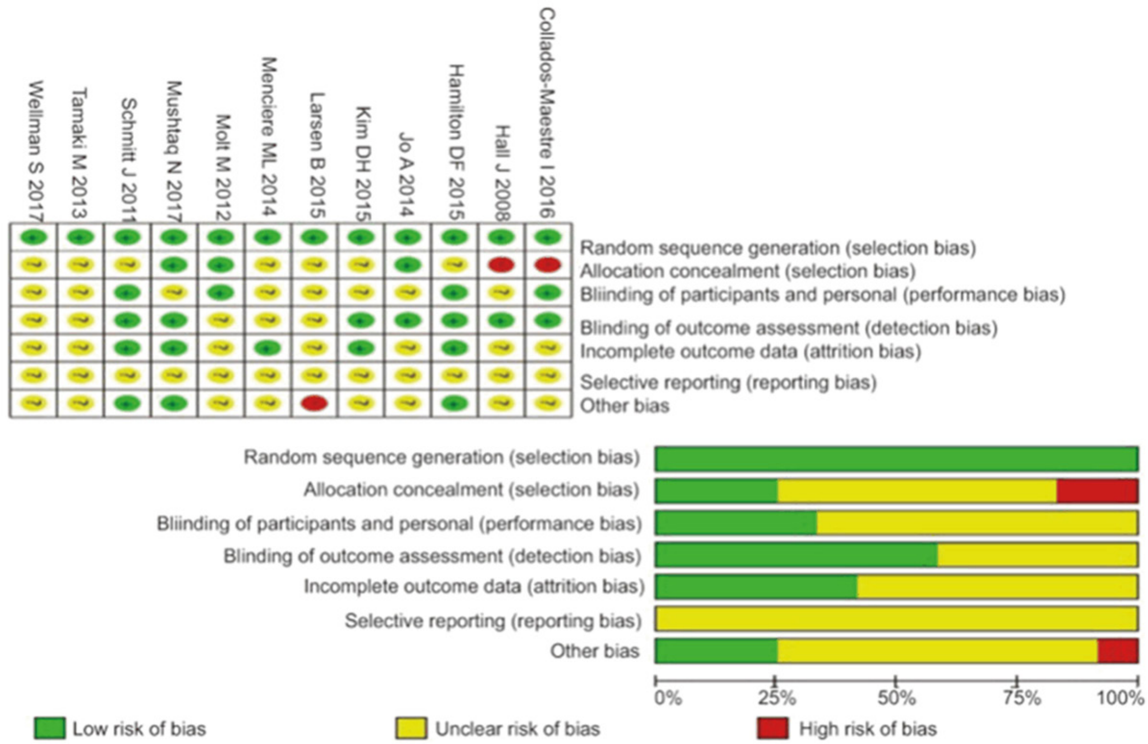

Figure 2. Graph showing risk of bias assessment bias. Low risk: +; high risk: -; unclear:?

were not detected in the meta-analysis: (1) Pain: WMD = 1.04; 95% CI = -17.14 to 19.22 (*P* = 0.91); (2) Symptoms: WMD = 4.03; 95% CI = -16.00 to 24.05 (*P* = 0.69); (3) ADL: WMD = -4.11; 95% CI = -26.04 to 17.81 (*P* = 0.71); (4) Sports: WMD = -6.21; 95% CI = -20.70 to 8.28 (*P* = 0.40); and (5) QOL: WMD = 3.57; 95% CI = -21.89 to 29.04 (*P* = 0.78).

OKS

This outcome assessment was available in 2 RCTs that reported OKS scores 1-year postoperatively (**Figure 6**). Differences were not statistically significant in the meta-analysis: WMD = -0.56; 95% CI = -3.97 to 2.84 (*P* = 0.75).

Range of motion, flexion, and extension

Two RCTs reported the range of motion using either an SR or MR design (**Figure 7A**). The meta-analysis showed significant differences between SR and MR groups. The SR group was superior to the MR group (WMD = 5.13; 95% CI = 2.69 to 7.58; *P* < 0.0001).

Five RCTs assessed postoperative flexion (**Figure 7B**). No significant differences were noted between SR and MR groups (WMD = -2.10; 95% CI = -10.02 to 5.81; *P* = 0.60).

Furthermore, 3 RCTs assessed postoperative extension (**Figure 7C**), with no significant differences detected between SR and MR groups (WMD = -0.23; 95% CI = -0.85 to -0.39; *P* = 0.47).

Gait

Two RCTs evaluated the gait cycle after TKA. Data regarding maximal flexion in the swing phase, maximal flexion in the stance phase, and minimal flexion in the stance phase were extracted (**Figure 8**). Maximal flexion in the swing phase did not show any significant differences between SR and MR groups (WMD = -3.13; 95% CI = -0.27 to 6.53; *P* = 0.07). Maximal flexion in the stance phase did not show any significant differences between SR and MR groups (WMD = 3.56; 95% CI = -0.44 to 7.55; *P* = 0.08. Minimal flexion in the stance phase did not show significant differences between SR and MR groups (WMD = 2.76; 95% CI = -2.41 to 7.94; *P* = 0.30).

Chair tests

Some of the included RCTs evaluated the extensor, postoperatively. Chair tests were applied to evaluate patient abilities to rise from an unfold-

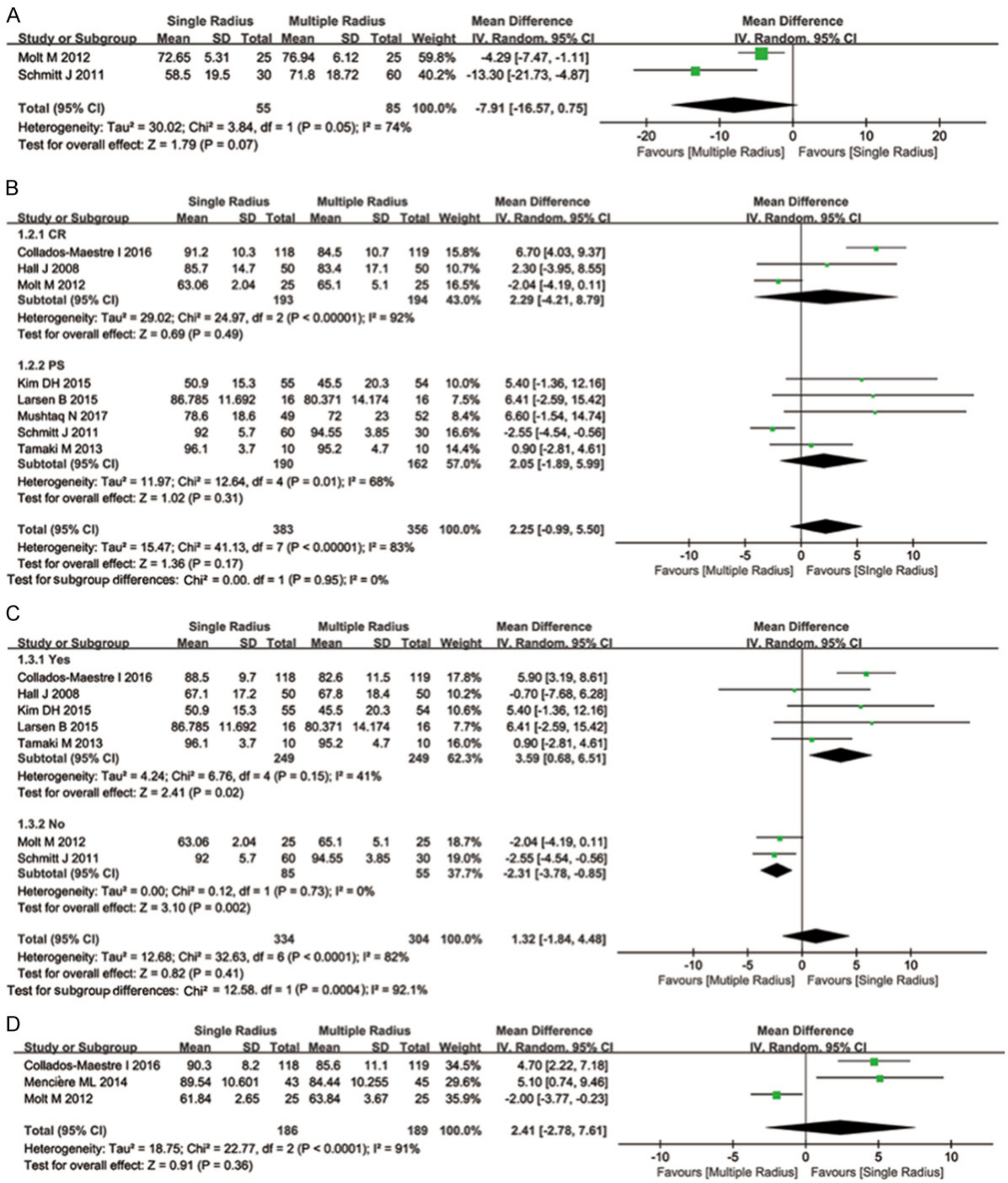

Figure 3. Forest plot of KSS knee: (A) 3-month follow-up; (B) 1-year follow-up with sub-analysis of different protheses types; (C) 1-year follow-up with sub-analysis of whether performing patellar resurfacing; (D) 2-year-follow-up. Statistically significant differences were detected in patellar resurfacing and no patellar resurfacing subgroups, with opposing results. No significant differences were detected in other subgroups (Knee Society Score, KSS; CR, cruciate ligament retaining; PS, posterior stabilizing; SD, standard deviation; IV, inverse variance; CI, confidence interval; df, degree of freedom).

ed chair, independently, indicating extensor function. Two RCTs reported a subset of patients that underwent chair tests successfully, showing significant differences between SR and MR groups (OR = 2.03; 95% CI = 1.13 to 3.64; P = 0.02) (**Figure 9**).

Complications

Of all the RCTs, six types of complications were associated with prostheses, including infections, aseptic loosening, deep venous thrombosis, instability, stiffness, and anterior knee

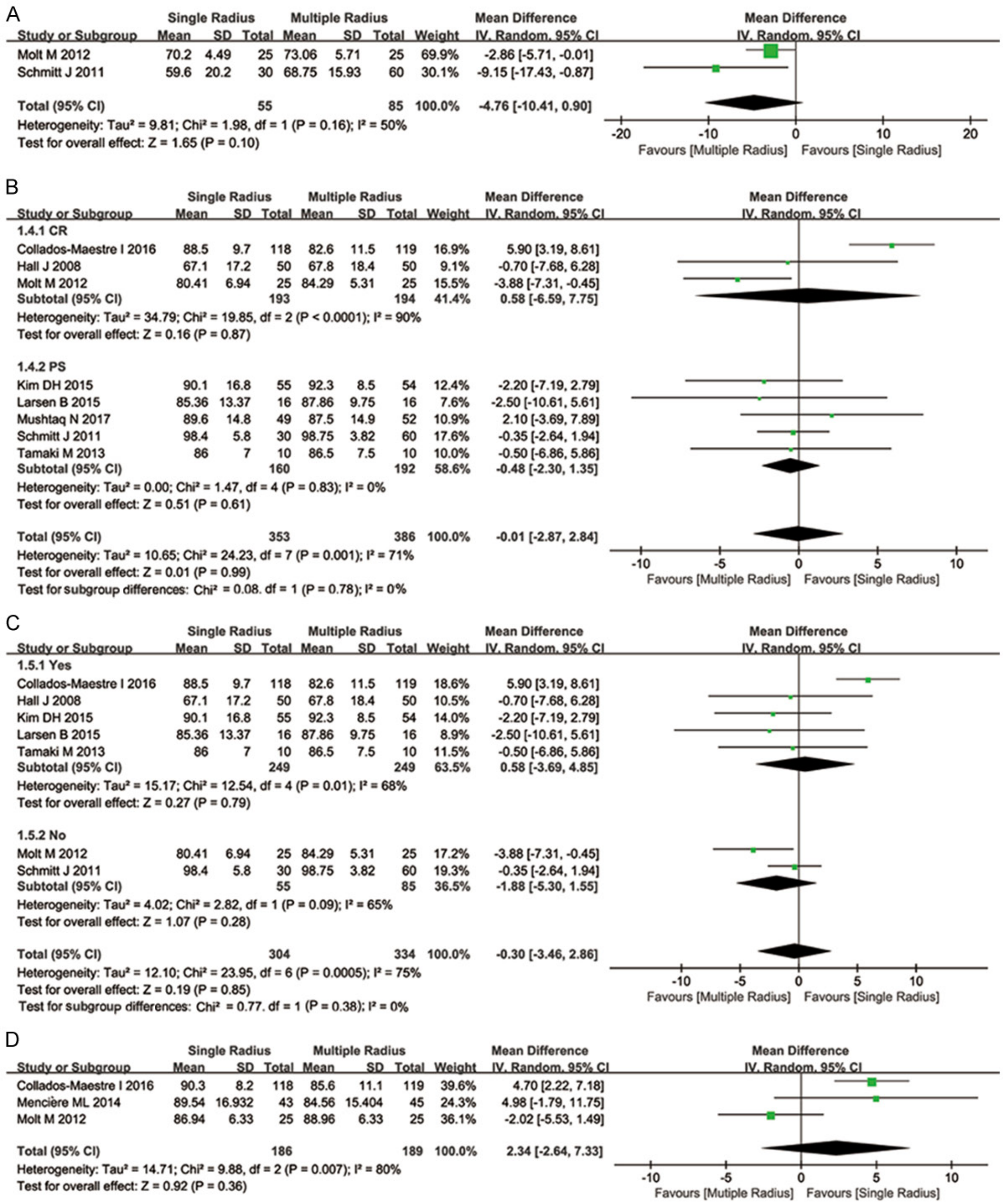

Figure 4. Forest plot of KSS function: (A) 3-month follow-up; (B) 1-year follow-up with sub-analysis of different protheses types; (C) 1-year follow-up with sub-analysis of whether performing patellar resurfacing; (D) 2-year-follow-up. No significant differences were detected in all the subgroups (Knee Society Score, KSS; SD, standard deviation; IV, inverse variance; CI, confidence interval; df, degree of freedom).

pain. However, deep venous thrombosis and instability were reported in only 1 RCT each.

Four RCTs reported incidence of infections. Moreover, 3/263 knees (1.1%) in the SR group and 5/276 (1.8%) in the MR group were diagnosed with infections, superficial or deep. Statistically significant differences were not detected in the groups (OR = 0.68; 95% CI = 0.17 to 2.74; $P = 0.59$) (**Figure 10A**).

Aseptic loosening was diagnosed in 2/148 knees (1.4%) in the SR group and 3/176 knees (1.7%) in the MR group, without significant dif-

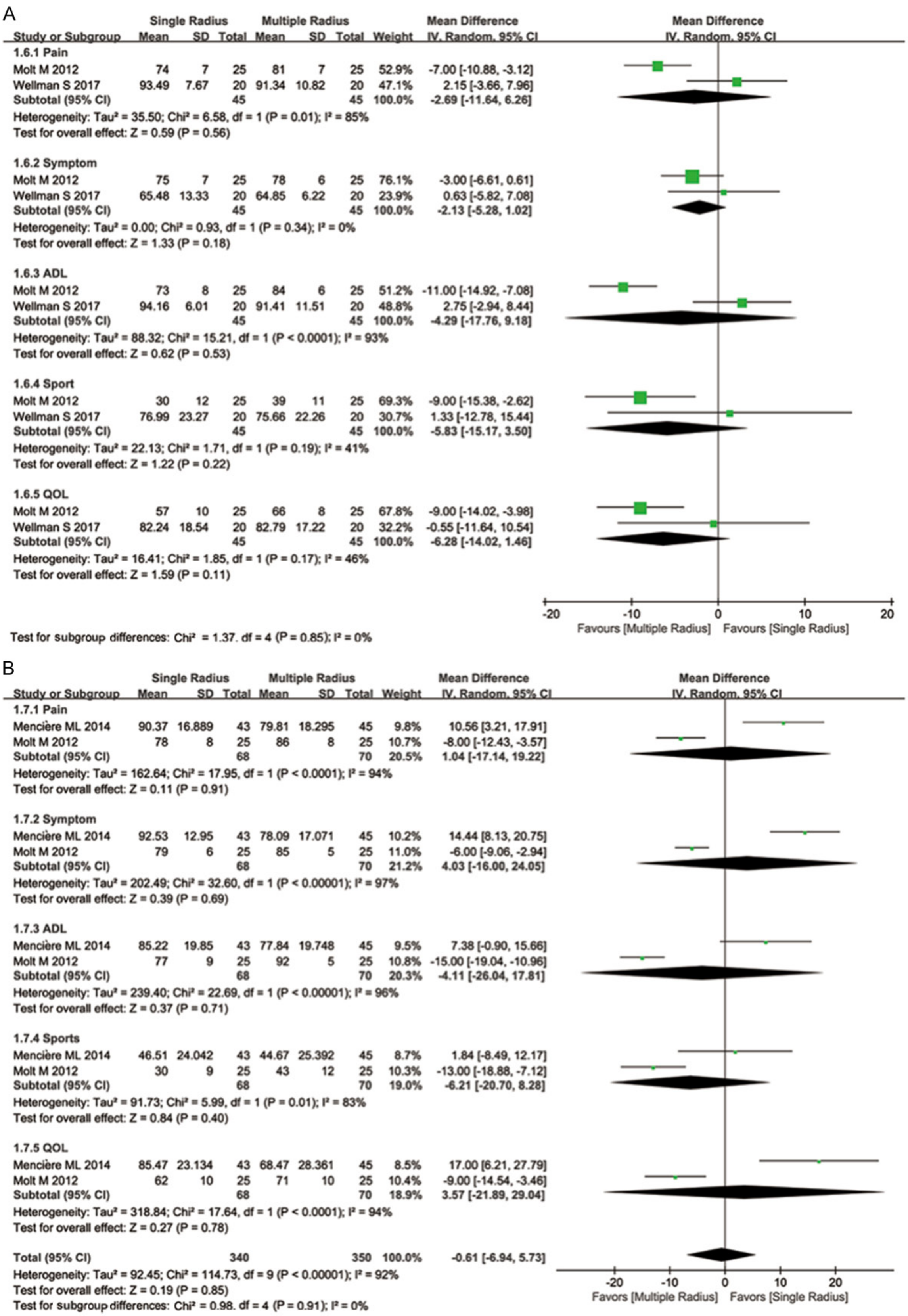

Figure 5. Forest plot of KOOS of 1 year (A) and 2 years (B). Difference were not significant in terms of pain, symptom, ADL, sports, and QOL (Knee Injury, and Osteoarthritis Outcome Score, KOOS; ADL, ability of daily living; QOL, quality of life; SD, standard deviation; IV, inverse variance; CI, confidence interval; df, degree of freedom).

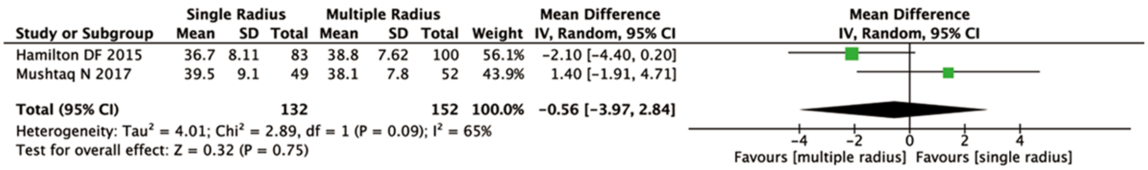

Figure 6. Forest plot of OKS of 1 year. No significant differences were detected (Oxford Knee Scores, OKS; SD, standard deviation; IV, inverse variance; CI, confidence interval; df, degree of freedom).

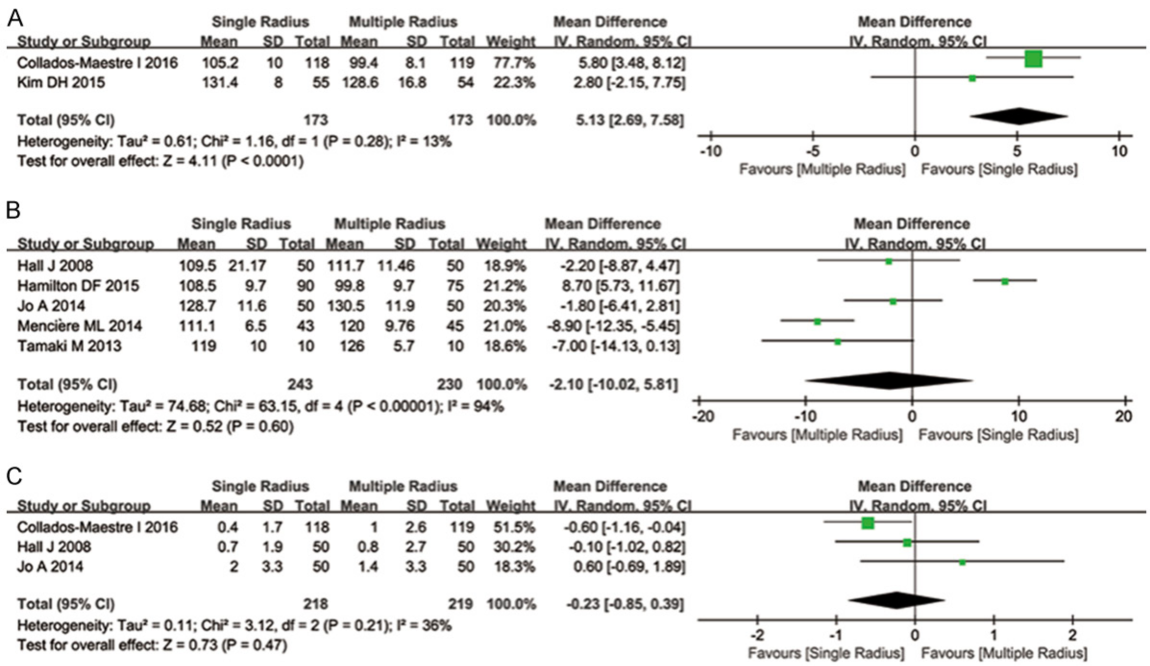

Figure 7. Forest plot of range of motion: (A) Comparing range of motion, there was a significance difference between the SR and MR groups, with SR group superior to the MR group. No significant differences were detected when comparing (B) flexion and (C) extension between the two groups (SD, standard deviation; IV, inverse variance; CI, confidence interval; df, degree of freedom).

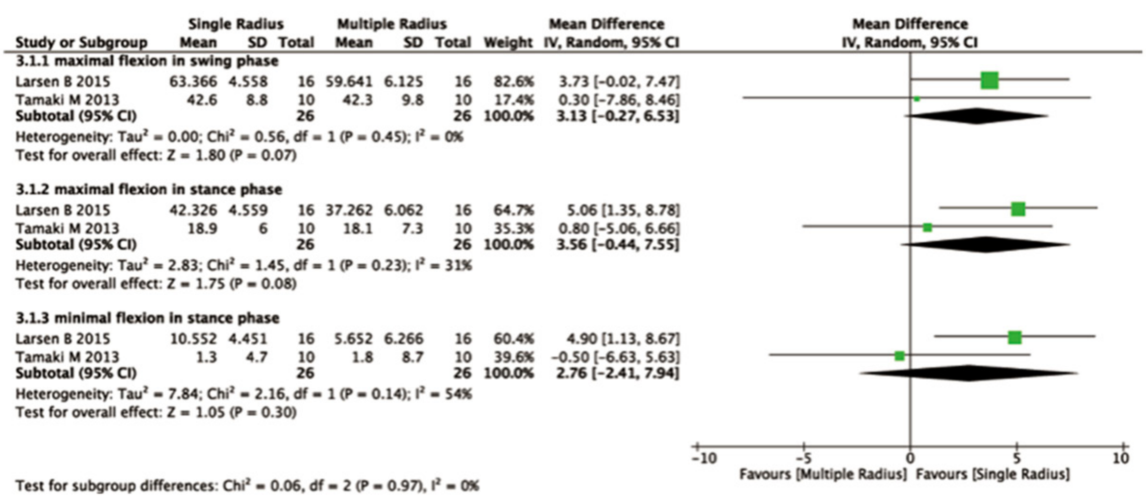

Figure 8. Forest plot of gait: maximal flexion in swing phase, maximal flexion in stance phase, and minimal flexion in stance phase. No significant differences between SR and MR groups were detected (SD, standard deviation; IV, inverse variance; CI, confidence interval; df, degree of freedom).

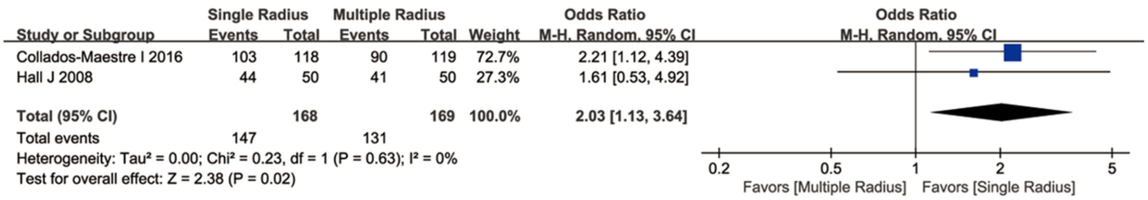

Figure 9. Forest plot of chair tests. No significant differences between SR and MR groups were found (M-H, Mantel Haenszel test; CI, confidence interval; df, degree of freedom).

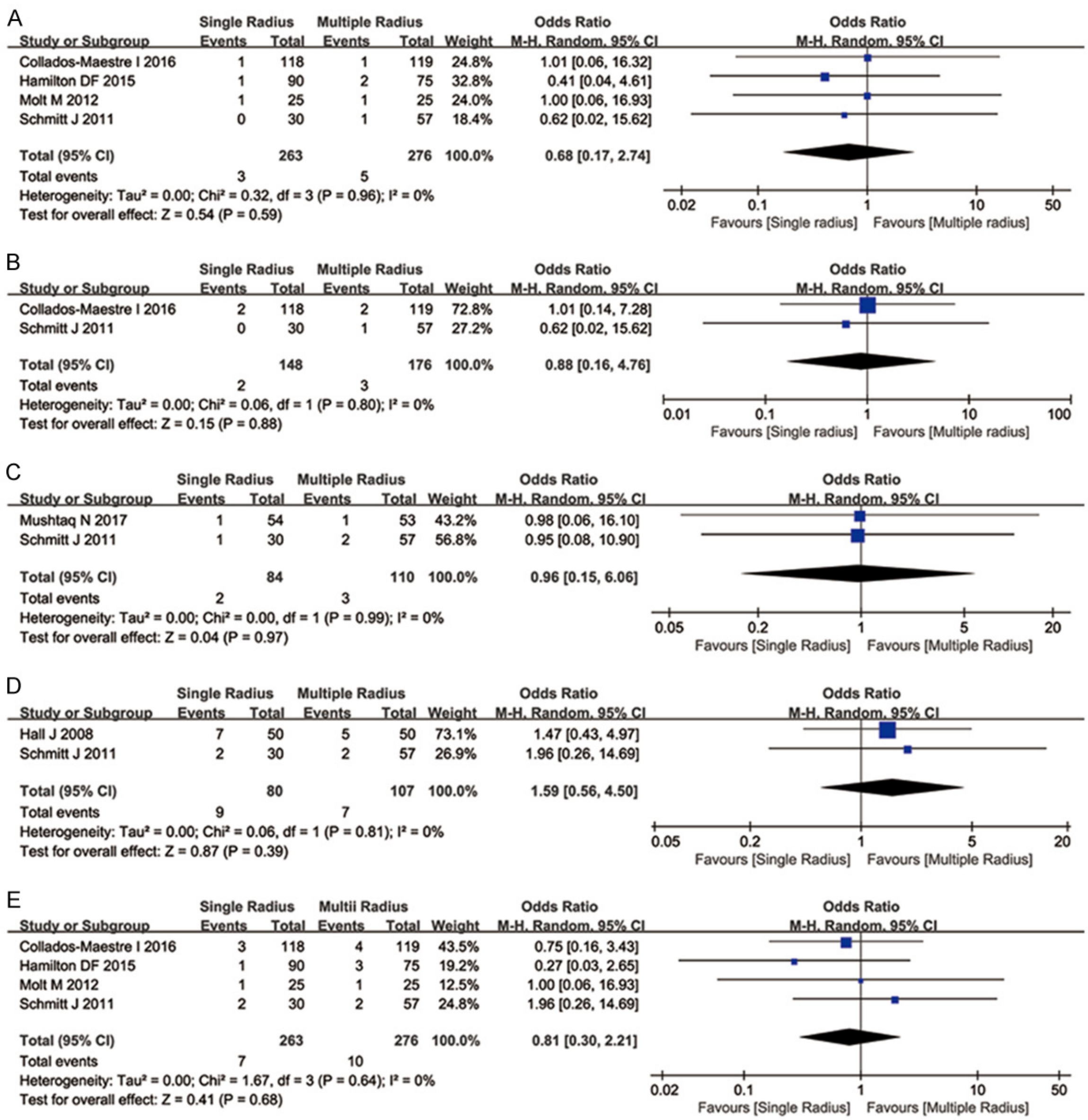

Figure 10. Forest plots of complications and revision: (A) infections; (B) aseptic loosening; (C) stiffness; (D) anterior knee pain; (E) revision. No significant differences were found between SR and MR groups in all the subgroups (M-H, Mantel Haenszel test; CI, confidence interval; df, degree of freedom).

ferences (OR = 0.88; 95% CI = 0.16 to 4.76; *P* = 0.88) (**Figure 10B**).

Two RCTs showed no significant differences in stiffness between the SR and MR groups.

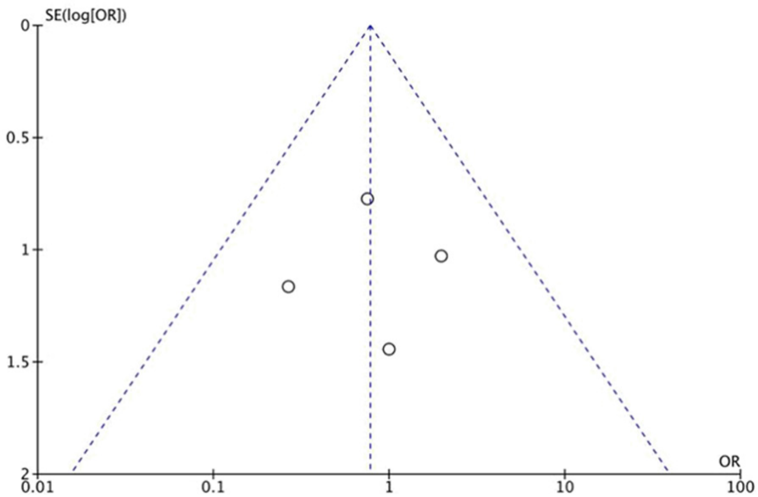

Figure 11. Funnel plot of comparison of revision rates between SR and MR groups. There was no visible publication bias in the funnel plot.

Moreover, 2/84 knees (2.4%) in the SR group and 3/110 knees (2.7%) in the MR group were diagnosed with stiffness, without significant differences (OR = 0.96; 95% CI = 0.15 to 6.06; P = 0.97) (**Figure 10C**).

Two RCTs reported anterior knee pain, with 9/80 knees (11%) in the SR group and 7/107 knees (6.5%) in the MR group. However, no significant differences were detected between the two groups (OR = 1.59; 95% CI = 0.56 to 4.50; P = 0.39), according to a fixed-effects model (**Figure 10D**).

Revision rates were reported in 4 RCTs. Moreover, 7/263 knees (2.7%) in the SR group and 10/276 knees (3.6%) in the MR group were revised, although no significant differences were detected (OR = 0.81; 95% CI = 0.30 to 2.21; P = 0.61) (**Figure 10E**).

Publication bias

A funnel plot of standard error was constructed based on the effect size for revision rates. Scatter points in the plot were distributed around the middle line, indicating that publication bias was not severe (**Figure 11**).

Discussion

In the current meta-analysis, no significant differences were observed comparing clinical scores in KSS-function and KOOS scores. However, for 1-year follow-up results of KSS-knee scores, statistically significant differences were detected in the patellar resurfacing subgroup in favor of SR. The no patellar resurfacing subgroup showed opposing results. Significant differences were detected in ROM and chair tests in favor of SR.

The SR implant is favorable, as it can optimize extensor function. D'Lima et al. [34] reported approximately 1 cm posterior of the femorotibial contact point in the Scorpio System with an SR design, compared to its predecessor, lowering the quadriceps and patellofemoral forces required in the knee extension. In another cadaveric study, the SR knee required 57% less quadriceps force, compared to the MR knee [35]. Collados-Maestre et al. [14] showed that the SR group had significantly better quadriceps strength than the MR group. Gómez-Barrena et al. [27] conducted an isokinetic study. They observed better extensor performances with decreased flexion peak torque and increased extension peak torque in patients with the SR design. Mahoney et al. [36] found that 90% of patients in the SR group could rise from a folded chair, independently, at 2 years, indicating improved extensor function. The current study found significantly better independent completion of chair tests in the SR group, compared to the MR group.

Some studies have found that the SR prosthesis could reproduce kinematics approximated to the natural knee during gait. Larsen et al. [16] compared the gait of SR and MR TKA, along with controls. They demonstrated, that 1 year postoperatively, SR knees did not differ from controls, while MR knees remained extended during the stance phase of the gait. This indicated a less compliant knee following heel strikes. The MR group also achieved less peak knee flexion than the control group during the swing phase. Power absorption during the stance phase for the MR group remained significantly lower from that in the controls, indicating that fewer eccentric forces were absorbed by the knee. In this study, no significant differences were detected in any phases of gait cycle. However, a high range of motion was found in the SR group. According to Mugnai et al. [29], this result was probably related to the slight instability in the MR design during motion. Hamstrings and capsules contract to compensate for the laxity of the knee. Excessive mechanical stresses on the soft tissues stimulate fibrous hyperplasia and knee joint synovitis with consequent knee stiffness, leading to a loss of ROM.

Current trials with large sample sizes, regardless of design, have shown optimistic results in favor of the SR design. Cook et al. [24] compared 426 cases of SR and 113 cases of MR designs at 3.9-year mean follow-up. They reported that the SR group had a significantly better KSSs, flexion, stability, pain, gait, and stair climbing than the MR group. Similarly, Palmer et al. [26] compared 388 cases of SR and 674 cases of MR. They found significantly better flexion and KSSs in the SR group at either 1- or 2-year follow-up, compared to the MR group, with 66.3% patients not experiencing any pain at 2 years, compared to 54.4% patients with MR knees. Collados-Maestre et al. [14] conducted an RCT comparing clinical outcomes with the largest sample size. They reported significantly better KSSs, range of motion, extension lag, quadriceps strength, chair tests, and WOMAC pain scores, as well as a higher satisfaction rates, in the SR group, compared to the MR group. In the current study, contradictory results were found in 1-year follow-up KSS-knee scores regardless of the resurfacing of the patella. This phenomenon might be attributed to the increased tension of lateral patellofemoral ligaments as a result of less roll-back and external rotation in the SR group, compared to the MR group. Moreover, the current study could not detect differences in other aspects of clinical scores, which might be attributed to the following: (1) Either SR or MR implant designs were not consistent through the trials. However, trials using the new-generation implants showed favorable results; (2) Several confounding factors should be taken into consideration; and (3) Clinical outcomes are also related with the complexity of the surgery, soft tissue balancing, and the prosthesis positioning. These are hardly reflected in function scores.

The current meta-analysis had some limitations. First, different types of prostheses of different manufacturers were used in these trials. This might have influenced the final results. Second, the sample sizes may not have been sufficient to detect differences in some parameters, such as complications, revision rates, and gait. Thus, due to the limited number of subjects, present conclusions are not persuasive. Third, some results led to large confidence intervals. Additional studies are necessary to verify the exact influence of protheses types on outcomes of knee function.

Despite these flaws, the current meta-analysis included only level data. Results suggest that SR prostheses in TKA greatly improve ROM and superior extensor function.

Acknowledgements

This study was supported by the Frontier and Key Technologies Innovation Funding Project of Department of Science and Technology of Guangdong Province (No. 2015B020225007); the National Natural Science Foundation of China Grant Awards (No. 81802222); the Natural Science Foundation of Guangdong Province (No. 2018A030310694); the Project of Administration of Traditional Chinese Medicine of Guangdong Province (No. 20191004).

Disclosure of conflict of interest

None.

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