REVIEW ARTICLE

Patellar Resurfacing in Primary Total Knee Arthroplasty: A Meta-analysis and Trial Sequential Analysis of 50 Randomized Controlled Trials

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Objective: During total knee arthroplasty, femur and tibia parts are regularly replaced, while resurfacing the patellar or not is an ongoing discussion. To compare revision rate, anterior knee pain rate, patient-reported outcome measures, complication, radiographic, and clinical outcomes after patellar resurfacing versus non-resurfacing in total knee arthroplasty.

Methods: PubMed, Medline, EMBASE, CENTRAL, and CINAHL databases were searched on 25 April 2021 to enroll randomized controlled trials that compared patellar resurfacing versus non-resurfacing. We used the grading of recommendations assessment, development and evaluation (GRADE) framework to assess the certainty of evidence. Our primary outcome was revision rate and secondary outcomes was anterior knee pain rate. Outcomes were pooled using the random-effect model and presented as risk ratio (RR), or mean difference (MD), with 95% confidence interval (CI).

Results: Fifty studies (5586 knees) were included. Significant reductions in patellar revision rate (RR 0.41, 95% CI [0.19, 0.88]; $P = 0.02$; $I^2 = 24.20\%$) and non-patellar revision rate (RR 0.64, 95% CI [0.55, 0.75]; $P < 0.001$; $I^2 = 0\%$) were seen after patellar resurfacing. Patellar resurfacing significantly reduced the anterior knee pain rate than nonresurfacing (RR 0.72, 95% CI [0.57, 0.91]; $P = 0.006$; $I^2 = 69.5\%$). Significant differences in patient-reported outcome measures were found. However, these differences were inconsistent and lacked clinical importance. Patellar resurfacing resulted in a significant lower rate of patellar clunk (RR 0.58, 95% CI [0.38, 0.88]; $P = 0.01$; $I^2 = 0\%$), a higher patellar score (MD 1.24, 95% CI [0.67, 0.81]; $P < 0.001$; $I^2 = 73.8\%$), but prolonged surgical time (MD 8.59, 95% CI [5.27, 11.91]; $P < 0.001$; $I^2 = 88.8\%$).

Conclusions: The clear relationship is that patellar resurfacing reduces revisions, anterior knee pain, and patellar clunk. It will be interesting to compare the initial cost with the revision cost when required and cost-utility analysis with long-term results in future studies.

Key words: Meta-analysis; Patellar resurfacing; Randomized controlled trials; Total knee arthroplasty

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Introduction

Total knee arthroplasty (TKA) is an established surgical procedure to treat end-stage knee arthritis.[1] The femur and tibia parts are regularly replaced during the surgery, while patellar resurfacing remains controversial.[2] Surgeons who recommend patellar resurfacing cited that the procedure could reduce anterior knee pain and secondary revision; however, complications were the main concern after replacing (i.e., patellar fracture, loosening, and instability).[2–11] Researchers who favored nonresurfacing believed that it could help bone preservation, shorten surgery time, and reduce material costs. Nevertheless, patients who had nonresurfacing always complained the anterior knee pain and necessitated secondary revision, thereby increasing the risk of infection and relevant complications due to surgery.[2,4,5,7,8]

Thirteen meta-analyses have shown that patellar resurfacing reduced the risk of revision with reported risk ratios (RRs) varying from 0.28 to 0.71 while remaining in disagreement regarding anterior knee pain, patient-reported outcome measures, and complications.[2,3,5–9,12–17] The incidences of anterior knee pain and complications have declined over the past decade and were comparable between patellar resurfacing and patellar nonresurfacing in multiple trials.[18–40] The inconsistent results in previous studies indicated further investigations were needed as surgery techniques and prosthesis type have evolved (Table 1). Moreover, there were several limitations in previous studies: (i) the reported follow-up time points were relatively short (<5 years), leaving long-term effects unclear; (ii) no study did subgroup analysis based on confounding factors; and (iii) radiographic outcomes were not synthesized and analyzed before. The latest meta-analysis evidenced that patellar resurfacing was superior to patellar nonresurfacing in revision rates, the Knee Society Clinical Rating System (KSS) score, noise, and functional score, with similar results in the other outcomes.[3] However, we found that 18 additional randomized controlled trials (RCTs) were not included in their study after a thorough search.[18–38,40–68] The increased sample size could enable the evaluation of minor treatment effects and infrequent outcome measures. Furthermore, subgroup analysis was performed based on follow-up duration, sequential surgery, prosthesis type, and diagnosis, which might provide insight into long-term effects, surgery selection, and prosthesis usage.

The purpose of this study was first to compare the revision rate, anterior knee pain rate, patient report outcome measures, complication rates, radiographic results, and clinical outcomes between patellar resurfacing and patellar nonresurfacing. Second, we evaluated revision, anterior knee pain, and patient report outcome measures in different follow-up terms, surgery techniques, prosthesis, and primary diagnosis.

Methods

Search Strategy

The review was prospectively registered on PROSPERO (CRD42021252111) and was reported according to the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines.[69,70] We searched PubMed, Ovid, Embase, Cochrane, CBM, VIP, CNKI, WanFang, and CINAHL databases from inception to April 2021. Medical subject headings and keywords were as follow: (“arthroplasty, replacement, knee” [MeSH Terms] OR “knee arthroplasty” [Title/Abstract] OR “knee replac*” [Title/Abstract]) AND “patellar resurfac*” [Title/Abstract] OR “patellar replac*” [Title/Abstract] AND (randomized controlled trials as topic [MeSH Terms] OR random allocation [MeSH Terms] OR RCT [Text Word]). There was no restriction on languages or publication years. Reference lists of potentially eligible studies and review articles were also searched to identify additional literature.

Inclusion criteria followed the PICO principles: patients were those who received TKA; Intervention was patellar resurfacing; control measure was patellar nonresurfacing; and outcome was one of the predetermined outcomes in this study. When publications included overlapping reports of a single trial, we included non-repeated data from the reports. Exclusion criteria were no availability of full-text articles, letters, meeting proceedings, and case reports. Two authors independently screened records by titles and abstracts, and the other two authors read full texts of potentially eligible studies to determine eligibility. Any disagreements were resolved by consensus.

Data Extraction

Four reviewers extracted data independently in pairs, using a predefined data extraction file. The following baseline characteristics were extracted from the included studies: first authors; publication year; the number of knees randomized; mean age; body mass index; diagnosis; the severity of diseases; pre-surgery varus or valgus; and pre-surgery patellar thickness. The confounding information includes: outcomes reported; interventions in the nonresurfacing group; implant; surgery; material; cement; anesthesia; tourniquet; lateral release; approach; and surgeons were also collected. Missing data were sought rigorously by attempting to contact authors by e-mail.

Outcomes

The primary outcome was: (i) revision rates, which can be divided into patellar revision and non-patellar revision rates; the secondary outcomes were: (ii) anterior knee pain; (iii) patient reported outcome measures which included four questionnaires: Knee Society Clinical Rating System (KSS) (total score, clinical score, functional score), Oxford Knee Score (OKS), Knee Injury and Osteoarthritis Outcome Score (KOOS) (pain, symptom, activity of daily living, sports, quality of life), and Western Ontario and McMaster

TABLE 1 Details of the previously published meta-analysis on this subject

Author	Year	Studies	Knees	Quality	Outcomes included	Conclusions of meta-analysis
NICE et al.[2]	2020	28 RCTs	4261	Level II	Mortality, quality of life, patient-reported outcome measures, revision, infection, length of stay, reoperation, complications	No clear statement
Teel et al.[5]	2019	20 RCTs	4506	Level II	KSS knee component, KSS function component, reoperation rates, AKP, patient satisfaction, OKS, KOOS sub-scores, ROM	The only clear relationship is that knees that do not receive patellar resurfacing are more likely to receive reoperation, most often for secondary resurfacing. However, the disease burden of differing complication profiles associated with resurfacing and non-resurfacing groups remains unclear. Continuing to collect data from large, well-designed RCTs would be beneficial in guiding the management of the patella during TKA
Migliorini et al.[6]	2019	23 RCTs, 8 PCTs	4132	Level III	AKP, reoperations, clinical scores (HSS, KSS, and related subscales), ROM	Based on the main findings of this meta-analysis, patellar resurfaced TKA was demonstrated to have performed superior overall. Patellar resurfacing detected a lower rate of postoperative anterior knee pain and reoperation. Moreover, the resurfacing group showed greater HSS, KSS, and corresponding subscales values. In favor of the retaining group, a slightly better ROM was evidenced
Tang et al.[7]	2018	20 RCTs	2573	Level II	KSS knee component, KSS function component, reoperation rates, infection, AKP	Our study suggests that during the follow-up of 1 to 2 years, patella resurfacing can significantly increase the Knee Society Clinical Score and reduce the reoperation rates in patients with knee osteoarthritis
Longo et al.[8]	2018	35 RCTs	5584	Level II	AKP, reoperation rates, KSS knee component, KSS function component, HSS	Based on the outcome scores of KSS (Pain), KSS (Function), and HSS post-operatively, patellar resurfacing TKAs have performed better than non-resurfaced TKAs. The lower secondary operation and revision rates for patellar resurfaced TKAs also demonstrate that this technique is the more practical option. However, the full impact of patellar resurfacing still needs to be critically evaluated by more extensive randomized controlled trials with long-term follow-up
Grassi et al.[9]	2018	10 meta-analyzes	N/A	Level II	reoperation, AKP, KSS, complications, pain VAS score, pain during stairs climbing, IKS, satisfaction, infections, patellar tilt angle, patellar shift	Comparable outcomes were found when comparing patellar resurfacing and non-resurfacing in TKA. The higher risk of reoperations after non-resurfacing should be interpreted with caution due to the methodological limitations of the meta-analyses regarding search criteria, heterogeneity, and the inherent bias of more accessible indication to reoperation when the patella is not resurfaced

Abbreviations: AKP, anterior knee pain; HSS, hospital for special surgery; KOOS, knee injury, and osteoarthritis outcome score; KSS, knee society score; OKS, Oxford knee score; PCT, prospective controlled trial; RCT, randomized controlled trial; ROM, range of motion.

Universities Osteoarthritis Index (WOMAC) (pain, stiffness, function); (4) complications, which included patellar crepitus, clunk, fracture, tendon damage, dislocation, subluxation, other patellar complication, and infection; (5) radiographic results, which included patellar title angel, displacement, Insall–Salvati index, and patellar score; and (6) clinical outcomes, which included a range of motion, surgery length, blood loss, mortality, patient satisfaction, and patient preference.

Risk of Bias and the Certainty of the Evidence

Two authors independently rated the risk of bias of trials using the Cochrane Collaboration risk of bias tool.[69] Disagreements were resolved by consensus. The study checked for random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessors, incomplete outcome data, selective reporting, and other biases. We used the grading of recommendations assessment, development and evaluation (GRADE) framework to assess the certainty of evidence.[71] Six outcomes included patellar revision, non-patellar revision, anterior knee pain, clinical subscore, functional subscore, and the overall score of KSS were assessed. The certainty of evidence will be downgraded for study limitations, including the risk of bias, indirectness of evidence, inconsistency, imprecision of effect estimates, and other considerations. Discrepancies were resolved by consensus or discussion with the other authors. The certainty of the evidence was then classified as high, moderate, low, or very low.

Data Synthesis and Statistical Analysis

We conducted subgroup analysis in outcomes reported by more than 10 studies. The subgroup analysis was performed that addressed the duration of follow-up (short term [within 1 year], middle term [2 to 5 years], long term [6 to 10 years]), surgery sequential (unilateral TKA [Uni-TKA], bilateral TKA [Bi-TKA]), prosthesis type (cruciate-retaining [CR], posterior cruciate-substitute [PS]), and primary diagnosis (osteoarthritis [OA], rheumatoid arthritis [RA]). Dichotomous data were reported as absolute number and percentage, pooled by the Mantel–Haenszel method, and presented as the risk ratio (RR) with 95% confidence interval (CI). We extracted continuous data as mean and standard deviation, pooled them using the inverse variance weighting method, and presented them as mean difference (MD) with 95% CI. We used random effects models for all analyses. The predefined algorithm was used to estimate the standard deviation (SD) if the study had not reported it. We assessed statistical heterogeneity between studies by visual inspection of forest plots and by the χ^2 test and the I^2 statistic ($P < 0.05$ or $I^2 > 50\%$ was considered significant heterogeneity). Publication bias was assessed by creating funnel plots in outcomes enrolled in more than 10 studies, and we further assessed publication bias with Egger's statistical tests. Sensitivity analysis was performed when the results had high heterogeneity by omitting a single study ($I^2 > 70\%$). We used the overall effect Z test to determine the significance level for treatment effects ($P < 0.05$). Data analyses were performed using STATA 13.0 (StataCorp, College Station, TX, USA).

Trial Sequential Analysis

We performed trial sequential analysis (TSA) using TSA software (www.ctu.dk/tsa) on three outcomes (revision rate, anterior knee pain, and KSS). TSA tests the credibility of the results by combining the estimation of information size (a cumulative sample size of included RCTs) with an adjusted threshold of statistical significance for the cumulative meta-analysis. The required information size and meta-analysis monitoring boundaries were quantified, alongside adjusted 95% CIs. Diversity adjustment was performed according to an overall type I error of 5% and power of 80%.

Results

Search Results

Figure 1 shows a flowchart of the literature search and study selection. The initial search yielded 310 results, from which 158 duplicates were removed, resulting in 152 unique records. Following the eligibility criteria, 66 relevant papers were identified based on title and abstract. This resulted in the final inclusion of 50 studies for analyses in this systematic review.[18–25,27–38,40–65,67,68,72,73] Eight studies[32–34,40,44,45,49,54,59,63,64,67,68] reported on patient cohorts described in previously published articles and were excluded or merged with the original studies.[32,44,64,67,68]

Baseline Study Characteristics

The 50 studies assessed 5586 knees, of which 2779 patellar were resurfaced, and 2870 patellar were not resurfaced. The first article was published in 1989,[68] and the latest one was published in 2020,[18] and the follow-up duration ranged from 2 weeks to 10 years. The largest trial enrolled 5917 patients,[52] while the smallest recruited 28 patients.[26] The total number of women patients was 50.16% in the patellar resurfacing group and 49.84% in the non-resurfacing group. All the included patients were over 60 years old except in Jia *et al.*'s study (the average year was 57.2, ranging from 37 to 65).[24] Table 2 showed the baseline characteristics of all included RCTs, and Table 3 presented more confounding information regarding trial designs, surgery information, and anesthesia. The Table 3 provided conclusions and the follow-up duration of each study.

Risk of Bias

The risk of selection bias was the domain most frequently rated as a source of bias, with two studies at high risk, 11 at unclear risk, and 37 at low risk. The risk of performance bias was unclear in seven studies, high in six studies, and low in 37 studies. The other bias was low. Therefore, the overall risk of bias was considered moderate in the detection domain and low in the other five domains (Table 4).

Revision

The patellar revision rate was reported in 10 studies (n = 2890), and the pooled effect showed a lower rate (RR = 0.41, 95% CI [0.19, 0.88], $P = 0.02$, $I^2 = 24.20\%$) in the resurfacing knees compared with the non-resurfacing knees (Table 5).

The non-patellar revision rate was reported in 20 studies ($n = 4381$). The pooled effect showed that patellar resurfacing was associated with a significant reduction in non-patellar revision rate compared with patellar non-resurfacing (RR = 0.64, 95% CI [0.55, 0.75], $P < 0.0001$, $I^2 = 0\%$) (Table 5). Non-patellar revision occurred in 4.25% of patients after patellar resurfacing compared with 7.06% after non-resurfacing (risk difference 2.81%). The cumulative Z curve crossed both the conventional and the TSA boundary for benefit, and the boundary for futility exceeded the

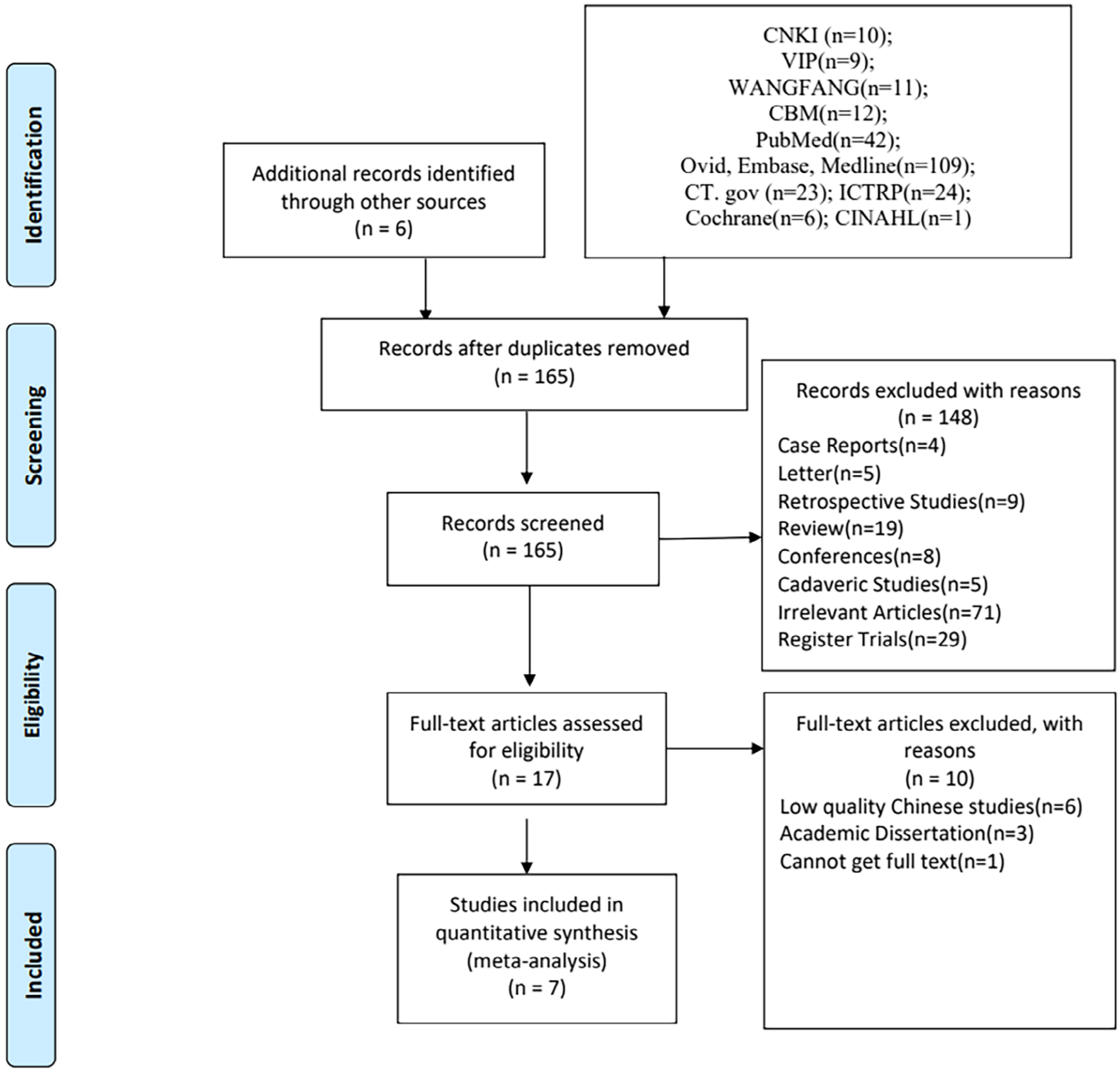

Fig. 1 PRISMA flow diagram representing search and selection of studies comparing patellar resurfacing versus patellar non-resurfacing of TKA

required information size (RIS) (Fig. 2). The certainty of evidence by the GRADE assessment was high (Supplementary Table 5).

Subgroup analysis found that the risk ratio favored patellar resurfacing up to 10 years postoperatively (<1 year: 4 studies, 440 knees, RR = 0.23, $P = 0.04$, $I^2 = 0\%$; 2–5 years: 22 studies, 4426 knees, RR = 0.59, $P < 0.01$, $I^2 = 11.1\%$; 6–10 years: 12 studies, 3515 knees, RR = 0.70, $P < 0.01$, $I^2 = 0\%$). Moreover, patellar resurfacing by cruciate retaining prosthesis (RR = 0.55, $P < 0.01$), and underwent unilateral surgery (RR = 0.59, $P < 0.01$) had lower revision rates than non-resurfacing. While in posterior substitute subgroup or bilateral surgery subgroup, the revision rates were similar between patellar resurfacing and non-resurfacing knees.

Anterior Knee Pain (AKP)

The pooled data of 4495 knees suggested the rate of AKP was lower in knees with patellar resurfacing than non-resurfacing (RR = 0.72, 95% CI [0.57, 0.91], $P < 0.01$, $I^2 = 69.54\%$). AKP occurred in 16.21% of patients after patellar resurfacing compared with 18.13% after non-resurfacing (risk difference 1.92%). The cumulative Z curve crossed both the conventional and TSA boundary for benefit and exceeded the RIS (Fig. 3). The GRADE certainty of the evidence was rated as moderate, being rated down 1 level due to concern regarding inconsistency given the high level of heterogeneity (Supplementary Table C).

Subgroup analysis found that the rate of AKP significantly reduced in resurfacing knees at short term (<1 year: 7 studies, 515 knees, RR = 0.55, $P = 0.03$, $I^2 = 30.4\%$) while

TABLE 2 Baseline characteristics of studies included in the meta-analysis of TKA

		Knees*		Age[†]		Gender (female[‡])	
Study (first author) and year	Study period	PR	PNR	PR	PNR	PR	PNR
Ali 2016 [30]	2008.02–2009.12	35	39	68 (4)	69 (4)	21 (60%)	24 (61.54%)
Aunan 2016	2007.11–2011.03	64	66	69 (42–82)	70 (48–82)	35 (55.55%)	38 (57.57%)
Bourne 1995[a1]	1991–1992	50	50	72 (7)	68 (7)	35 (70%)	23 (46%)
Barrack 1997[b1]	1992.01–1993.12	58	60	65.3 (27–82)	67.1 (30–87)	4 (15.38%)	2 (7.14%)
Barrack 2001[b2]				See in Barrack 1997			
Burnett 2004[a2]				See in Bourne 1995			
Burnett 2007[b3]				See in Barrack 1997			
Burnett 2009[b4]				See in Barrack 1997			
Breeman 2011[c2]				See in Johnston 2009			
Beaupre 2012	1996–1999	21	17	64.9 (4.0)	62.0 (5.6)	16 (76%)	10 (59%)
Campbell 2006	1991–1993	46	54	71 (53–88)	73 (54–86)	33 (71.74%)	39 (72.22%)
Chawla 2019	2011.06–2013.05	50	50	N/A	N/A	41 (82%)	39 (78%)
Dong 2018	2013.06–2015.03	53	53	67.7 (6.2)		30 (57%)	
Deroche 2021	2017.04–2018.11	125	125	68.8 (7.8)	69.7 (8.3)	73 (59.3%)	70 (56.9%)
Eshnazarov 2016	2004–2013	62	61	66.3	65.6	N/A	N/A
Feller 1996	1990.11–1991.06	19	19	70.5 (6.6)	71.1 (5.6)	6 (30%)	11 (55%)
Ferguson 2015 (FB)[d1]	N/A	88	88	69.8 (8.16)		94 (53%)	
Ferguson 2015 (MB)[d2]	N/A	89	87	70.2 (7.60)		93 (53%)	
Ferguson 2014 (FB)[d3]				See in Ferguson 2015			
Ferguson 2014 (MB)[d4]				See in Ferguson 2015			
Gildone 2005	2002–N/A	28	28	74.6 (89–65)	73.6 (87–67)	19 (67.86%)	20 (71.43%)
Huang 2007	2000.01–2001.06	57	50	68.1 (52–84)	66.5 (55–81)	N/A	
Ha 2019	2011.03–2012.08	66	66	65.2 (5.4)		22 (36.7%)	
Jia 2018	2013.03–2015.08	30	30	57.2 (37–65)		6 (20%)	
Johnston 2009[c1]	1999.06–2003.01	861	854	70 (8)	70 (8)	474 (55.1%)	481 (56.3%)
Kajino 1997[e2]				See in Shoji 1989			
Kordelle 2003	1999.05–2000.05	25	25	N/A	N/A	N/A	N/A
Kaseb 2018	2012.01–2013.11	24	26	64.8 (7.8)		42 (84%)	
Kaseb 2019	2014.05–2017.02	29	44	68.1 (7.65)	65.75 (6.85)	38 (86.36%)	20 (68.96%)
Koh 2019	2012.12–2013.08	49	49	70 (5.8)		48 (97.96%)	
Liu 2007	2002.01–2002.12	30	30	68 (50-77)	68 (54-80)	25 (83.33%)	24 (80%)
Liu 2012	2000.01–2002.12	74	70	67.5 (7.2)	68.0 (6.7)	41 (60.29%)	42 (65.63%)
Mayman 2003	1991–N/A	50	50	72 (7)	68 (7)	15 (30%)	27 (54%)
Myles 2006	N/A	25	25	70 (9.2)		24 (48%)	
Murry 2014[c3]				See in Johnston 2009			
Newman 2000	1990.01–1992.09	42	42	71.2	72.5	25 (59.52%)	28 (66.66%)
Partio 1995	N/A	47	48	69 (58–78)	66 (40–83)	73 (76.84%)	73 (76.84%)
Rodríguez 2010	1995–2000	250	250	N/A	N/A	N/A	N/A
Roberts 2015	1996.07–2001.4	178	172	70.2 (8.7)	71.3 (7.4)	81 (45.5%)	89 (51.7%)
Raaij 2020	2012–2015	21	21	67.3 (8.6)	71.6 (8.0)	12 (57%)	14 (67%)
Schroeder-Boersch 1998	N/A	20	20	73.0 (62–79)	72.2 (59–79)	14 (70%)	14 (70%)
Shoji 1989[e1]	N/A	47	48	56.1(42-73)		N/A	N/A
Smith 2008	1998.02–2002.11	87	94	71.9 (54.4–88.1)	71.2 (52.9–84.9)	35 (48%)	44 (52%)
Sreehari 2014	2009–2014	75	60	68.1	65.8	41 (54%)	41 (67%)
Tabutin 2005 (France Group)	1981–1995	481	6	70.97		362 (74.4%)	
Tabutin 2005 (International Group)	1981–1995	2035	3393	69.89		4020 (69.7%)	
Thieng 2019	N/A	42	42	68.2 (8.2)	68.2 (8.0)	36 (87.80%)	30 (76.92%)
Vukadin 2017	N/A	30	30	68.1 (7.03)	66.6 (6.4)	16 (46.66%)	17 (43.33%)
Waikakul 2000	N/A	21	26	72.25 (9.01)	72.25 (9.01)	29 (61.70%)	29 (61.70%)
Wood 2002	1992.08–1996.05	92	128	73.7 (6.5)	73.7 (6.5)	104 (51%)	69 (54%)
Waters 2003	1992.09–	243	231	69.1 (35–89)		233 (59.74%)	233 (59.74%)
Wang 2017	2014–N/A	14	14	66.9 (7.8)		14 (100%)	
Yang 2013	2010.08–2010.11	35	34	66 (8.3)	65 (10)	6 (33.33%)	5 (26.31%)
Total number	N/A	2779	2807	N/A	N/A		

Abbreviations: BMI, body mass index; PNR, patellar non-resurfacing; PR, patellar resurfacing.; * *t* test was used to determain the difference of two groups regarding number of knees included ($P = 0.691$).; [a] Represents that the study was from the same trial, initially reported by Bourne in 1995 and had two follow-up report studies.; [b] Represents that the study was from the same trial, initially reported by Barrack in 1997 and had four follow-up report studies.; [c] Represents that the study was from the same trial, initially reported by Johnston in 2009 and had three follow-up report studies.; [d] Represents that the study was from the same trial, initially reported by Ferguson in 2015 and had two follow-up report studies.; [e] Represents that the study was from the same trial, initially reported by Shoji in 1989 and had two follow-up report studies.; [†] Data were presented as (mean ± SD) or (mean, range).; [‡] Data were presented as (number and percentage).

TABLE 3 The confounding factors of included studies

Study (first author) and year	Country	Patients (knees)	Outcome measures	Bi/Uni	Cement	System	PNR	Prothesis	Surgeon	Anesthesia	Tourniquet	Lateral release	Approach
Ali 2016	Sweden	74 (74)	Pain score (by VAS), KOOS, patient satisfaction, physical performance tests	N/A	All	Stryker Triathlon CR knee system	N/A	N/A	5	Spinal, general	All	N/A	MP
Aunan 2016	Norway	115 (129)	KOOS, KSS, OKS, VAS, patient satisfaction, deep SSI	Mix	All	NexGen; Zimmer, Warsaw, IN	P	CR, FB	1	N/A	Yes	S	MP
Bourne 1995 (a1)	Canada	90 (100)	KSS, KSS knee, KSS function, revision, 30-s stair climbing, hamstring torques	Mix	Hybrid	Hybrid anatomical modular knee (Anatomical Medullary Knee, DePuy, Warsaw, IN)	P	CR	N/A	N/A	Yes	S	MP
Barrack 1997 (b1)	America	89 (121)	KSS, patient satisfaction questionnaire, radiographs, revision	Mix	All	Miller-Galante II; Zimmer, Warsaw, Indiana	P	CR	1 group	N/A	Yes	S	N/A
Barrack 2001 (b2)	America	86 (118)	KSS, patient satisfaction questionnaire, radiographs	Mix	All	Miller-Galante II; Zimmer, Warsaw, Indiana	P	PS	1 group	N/A	Yes	S	N/A
Burnett 2004 (a2)	Canada	90 (100)	KSS, KSS knee, KSS functional (stair climbing, flexion/extension patellar examination), patient satisfaction, AKP, revision patellofemoral questionnaires	Mix	Hybrid	Hybrid anatomical modular knee (Anatomical Medullary Knee, DePuy, Warsaw, IN)	P	CR	N/A	N/A	Yes	S	MP
Burnett 2007 (b3)	America	32 (64)	KSS, AKP, patellofemoral functional activities, satisfaction	Bi	All	Miller-Galante II (Zimmer, Warsaw, Indiana)	P	PS	1 group	N/A	Yes	S	N/A
Burnett 2009 (b4)	America	57 (78)	KSS, patellofemoral questionnaire, patient satisfaction, global and AKP, radiographs, complications, reoperation, ROM	Bi	All	Miller-Galante II (Zimmer, Warsaw, Indiana)	P	CR	1 group	N/A	Yes	S	N/A
Breeman 2011 (c2)	England	1715	OKS, SF-12, EQ-5D, complications, revision, costs, cost-effectiveness	Uni	Hybrid	Mix	N/A	CR, PS	116	N/A	N/A	S	N/A
Beaupre 2012	Canada	38 (38)	WOMAC, RAND-36, ROM, reoperation, complications	Mix	All	Profix™ total knee system, Smith & Nephew Profix	No	CR, FB	3	N/A	Yes	N/A	MP
Campbell 2006	Australia	100 (100)	WOMAC, AKP, KSS, reoperation, radiographic, SSI, significant adverse events, patellofemoral questionnaire	Bi	Hybrid	Miller-Galante II (Zimmer, Warsaw, Indiana)	P	CR	1 group	N/A	N/A	S	N/A
Chawla 2019	India	100 (100)	KSS, KSS knee, KSS functional, AKP (VAS), complication, infection, radiography	Uni	All	Zimmer, Warsaw, Indiana	P+CE	N/A	1	Spinal, epidural	No	S	MP
Dong 2017	China	53 (106)	KSS, Feller Score, patient preference, radiograph (Insall–Salvati index, patellar tilt angle)	Bi	All	Smith & Nephew Genesis II Hi-flexion, London, UK	P+CE	PS	1	General	no	S	MP
Deroche 2021	France	245 (250)	KSS, KSS knee, KSS function, FJS, AKP, pain when climbing stairs, patellar tilt, patellar translation	Mix	All	Anatomic, AMPLITUDE®, Valence 26000, FRANCE	CE	PS, FB	2	N/A	no	S	Trans-quadriceps tendon
Eshnazarov 2016	Korea	91 (123)	Radiological outcomes (mechanical femorotibial angle, patellar tilt, congruence angles)	Mix	All	N/A	P + CE	N/A	N/A	N/A	N/A	N/A	MP
	England	176	KSS, OKS, SF-12, reoperation, ROM	Uni	All		N/A	PS	3 groups	N/A	Yes	S	N/A

TABLE 3 Continued

Study (first author) and year	Country	Patients (knees)	Outcome measures	Bi/Uni	Cement	System	PNR	Prothesis	Surgeon	Anesthesia	Tourniquet	Lateral release	Approach
Ferguson 2014 (Fixed) (d1)						PFC Sigma© Posterior Stabilized, DePuy, Warsaw, IN							
Ferguson201 4 (Mobile) (d2)						See in Ferguson 2014 (fixed group)							
Ferguson 2015 (Fixed) (d3)						See in Ferguson 2014 (fixed group)							
Ferguson 2015 (Mobile) (d4)						See in Ferguson 2014 (fixed group)							
Feller 1996	Australia	40 (40)	HSS, Patellar Score	Uni	Hybrid	Howmedica, Rutherford, New Jersey	P	N/A	1	N/A	N/A	No	MP
Gildone 2005	France	56	KSS, functional (patella-related activities), ROM, patient satisfaction, AKP	Uni	All	NexGen, Zimmer, Warsaw, Indiana, USA	P	CR, FB	1	N/A	N/A	N/A	N/A
Huang 2007	China	85 (107)	HSS, Patellar Score, SF-36, radiographs (Insall-Salvati index, congruence angle, patellar height)	Mix	N/A	Advantage Prothesis, Depuy, Wright Company, USA	P	CR	1 group	General	Yes	S	N/A
Ha 2019	China	66 (132)	KSS, Feller Score, AKP (by VAS), patellar clunk, function, patient satisfaction	Bi	All	Scorpio NRG knee prostheses, Stryker, USA	P	PS	1	Epidural	Yes	S	MP
Johnston 2009 (c1)	England	1715	OKS, SF-12, EQ-5D, complications, revision, costs, cost-effectiveness	Uni	Hybrid	Mix	N/A	CR, PS	116	N/A	N/A	S	N/A
Jia 2018	China	30 (60)	KSS, FJS, AKP, complications (patellar crepitus, patellar clunk), functional ability, radiograph	Bi	All	N/A	P + CE	N/A	1 group	General	Yes	S	MP
Kajino 1997 (e2)	Japan	26 (51)	HSS, pain with activities, tenderness of patellofemoral point	Bi	N/A	Biomet, Warsaw, Indiana	N/A	N/A	N/A	N/A	N/A	All	N/A
Kordelle 2003	German	N/A	HSS, KSS, AKP	Uni	All	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Kaseb 2018	Iran	50 (50)	KSS, KSS functional, KAKPS, WOMAC, SF-36, ROM, revision, VAS, radiograph, complications, release rate lateral	Uni	All	Profix™ Total Knee System, Zimmer	P + CE	FB, PS	3	N/A	Yes	No	MP
Kaseb 2019	Iran	63 (73)	KSS knee, KSS function, KOOS, patellar crepitus	Mix	All	Zimmer® NexGen®	N/A	FB, PS	1	N/A	Yes	N/A	MP
Koh 2019	Korea	49 (98)	AKP, FJS, WOMAC, preference, Feller Score, ROM, radiography (patellar tilt, patellar displacement, Insall-Salvati ratio), patella-related complications, revision	Bi	All	Lospa, Corentec Co, Ltd., Seoul	No	PS	1	General	N/A	All	Sub-vastus
Liu 2007	China	60 (60)	KSS, AKP, ROM, patient satisfaction, radiograph	Uni	All	PFC, Sigma, Depuy Corp, USA	P + CE	N/A	1 group	N/A	N/A	S	MP
Liu 2012	China	144	KSS, AKP, radiograph	Uni	All	Press Fit Condylar, DePuy, Warsaw, IN	P + CE	PS	1 group	N/A	N/A	S	MP
Mayman 2003	Canada	90 (100)	KSS, AKP, satisfaction	Uni	All	Anatomic Medullary Knee, DePuy, Warsaw, IN	No	CR	N/A	N/A	N/A	S	N/A
Myles 2006	England	50 (50)	KSS, WOMAC, pain (VAS), functional activity	Uni	N/A	DePuy, Ltd, Leeds, UK	N/A	N/A	2	N/A	N/A	N/A	N/A

Murray 2014 (c3)	England	1715	OKS, SF-12, EQ-5D, complications, revision, costs, cost-effectiveness	Uni	N/A	Mix	N/A	N/A	116	N/A	N/A	S	N/A
Newman 2000	England	71 (71)	Bristol Knee Score, Clinical Patella Score, radiographs, revision, complications, mortality,	Uni	All	Howmedica, Rutherford, New Jersey, USA	N/A	PS	3	N/A	Yes	All	MP
Partio 1995	Finland	95 (95)	KSS, HSS, ROM, subjective assessment, patellar score, deep SSI, major adverse events	Uni	Hybrid	J&J Press Fit Condylar	P	CR	1	General	no	N/A	MP
Rodríguez 2010	Spain	250 (500)	Revision	Bi	All	Zimmer, Warsaw, Indiana	N/A	PS	2	N/A	N/A	N/A	MP
Roberts 2015	America	270 (350)	Patient satisfaction, revision, KSS, ROM, AKP, stair climbing, revision, SSI (superficial, deep)	Mix	All	DePuy Sigma knee system	P	FB, CR	N/A	Spinal	N/A	S	MP
Raaij 2020	Netherlands	40 (42)	HSS Baldini Score, KSS, KOOS	Mix	All	AGC Total Knee System, Biomet, Warsaw, IN	P + CE	CR	2	N/A	N/A	N/A	MP
Schroeder-Boersch 1998	German	36 (40)	KSS, radiograph, reoperation, patella morphology, and position	Mix	Hybrid	Duracon TKA system, Howmedica	P	N/A	N/A	N/A	N/A	No	N/A
Shoji 1989 (e1)						See in Kajino 1997							
Smith 2008	Australia	142 (181)	KSS, AKP, stair climbing, rising from sitting, patient satisfaction, revision, reoperation	Mix	All	Profix total knee system (Smith & Nephew Richards Inc., Memphis, Tennessee)	P	N/A	3	N/A	N/A	S	N/A
Sreehari 2014	India	135 (135)	KSS, Clinical Anterior Knee Pain Rating, patient satisfaction, global and anterior knee pain scores, radiography, complications, revisions	Uni	N/A	N/A	N/A	N/A	N/A	N/A	N/A	S	N/A
Tabutin 2005 (France)	France	487	PF pain, rate of lateral retinacular release	Uni	Hybrid	Nex Gen (Zimmer, Warsaw, USA)	P	PS, CR, FB	1 group	N/A	N/A	S	N/A
Tabutin 2005 (International)	Multiple countries	See in Tabutin 2005 (France)											
Thieng 2019	Thailand	84 (84)	Patellar crepitus, ROM, KSS, OKS, Patellar Score, radiography	Uni	All	Legion PS Total Knee System, Smith & Nephew, Memphis, TN	N/A	FB, PS	1	Regional	Yes	N/A	Mini-mid-vastus
Vukadin 2017	Serbia	60 (60)	KSS, OKS, pain (VAS)	Uni	All	Zimmer Nexgen LPS-type	P	FB, PS	1 group	N/A	N/A	All	MP
Waikakul 2000	Thailand	47 (47)	Joint position sense, AKP, KSS	Uni	All	N/A	N/A	CR	1 group	General	No	N/A	MP
Wood 2002	Australia	201 (220)	KSS, revision, reoperation, specific evaluation of AKP, stair climbing, radiography	Mix	All	Zimmer Miller-Galante II	P	CR	6	N/A	N/A	S	MP
Waters 2003	England	431 (514)	KSS, clinical AKP rating, patient-satisfaction score	Mix	All	Press-Fit Condylar prosthesis, Johnson, Raynham, Massachusetts	P	PS, CR	N/A	N/A	N/A	S	MP
Wang 2017	China	14 (28)	KSS, ROM, patellar tilt angle	Bi	All	N/A	P + CE	N/A	1 group	General	Yes	S	MP
Yang 2013	China	48 (69)	KSS, Patellar Score, AKP, radiography, complications	Mix	All	Scorpio Prosthesis, Stryker, USA	P + CE	PS	1 group	N/A	Yes	S	MP

Abbreviations: AKP, anterior knee pain; AMK, anatomic modular knee; Bi, bilateral TKA; CE, circum-patellar electrocautery; CORR, clinical orthopaedics, and related research; CR, cruciate-retaining; EQ-5D, EuroQol five-dimensional questionnaire; FB, fixed bearing; FJS, forgotten joint score; HSS, hospital for special surgery score; IC, Iwano classification; ICRS, international cartilage repair society; KAKPS, Kujala anterior knee pain scale; KL, Kellgren–Lawrence; KOOS, knee injury and osteoarthritis outcome scores; KSS, knee society scores; MB, mobile-bearing; MP, medial parapatellar; OA, osteoarthritis; OKS, Oxford knee score; P, patelloplasty; PF, patellar-femoral; PNR, patellar non-resurfacing; PR, patellar resurfacing; PS, posterior substitute; RAND-36, health survey distributed by RAND corporation; ROM, range of motion; S, selective; SF-12, short form questionnaire-12 items; SSI, surgical site infection; Uni, unilateral TKA; VAS, visual analog scale; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

there was no difference was found at the middle or long term. Lower rates of AKP with uni-TKA (RR = 0.60, $P = 0.04$) and CR prosthesis (RR = 0.60, $P = 0.01$) were evidenced after patellar resurfacing. The primary diagnosis did not affect the benefit of resurfaced patellar (OA, RR = 0.78, $P = 0.02$; RA, RR = 0.02, $P < 0.01$) (Table 6).

Patient-Reported Outcome Measures (PROMs)

Knee Society Scores (KSS)

A higher KSS total score was evidenced but was not significant (MD = 1.87, $P = 0.24$) in knees with patellar resurfacing. For the clinical part, knees with patellar resurfacing were associated with a higher score ($n = 4520$, MD = 0.62, 95% CI [0.21, 1.03], $P = 0.003$, $I^2 = 29.60\%$) (Table 5). The cumulative Z curve crossed the futility boundary and exceeded the required information size (RIS) (Fig. 4). Subgroup analysis suggested that the resurfacing knees had higher KSS clinical scores than non-resurfacing knees, with benefits lasting to 10 years, after bilateral TKA (MD = 1.03, $P < 0.0001$), and with posterior substitute prosthesis (MD = 0.73, $p = 0.002$; Table 6). Moreover, resurfacing knees were associated with a higher functional score of KSS ($n = 4256$, MD = 1.45, 95% CI [0.72, 2.19], $P < 0.0001$, $I^2 = 39.30\%$) (Table 5; Fig. 5). Subgroup analysis showed that the result favored resurfaced knees up to 5 years (<1 year: 14 studies, 894 knees, MD = 1.11, $P = 0.03$, $I^2 = 0\%$; 1–5 years: 36 studies, 4189 knees, MD = 1.46, $P < 0.01$, $I^2 = 51.6\%$) while there was no difference in the long-term period. In bilateral TKA (MD = 1.72, $P < 0.0001$) and PS prosthesis (MD = 1.78, $P < 0.0001$) subgroups, the resurfaced knees had higher KSS functional scores than non-resurfaced knees (Table 6). And the quality of evidence were "high" for both clinical and functional KSS scores (Supplementary Table C).

Oxford Knee Score (OKS)

The resurfaced knees had higher OKS scores compared with non-resurfaced knees (MD = 0.48, 95% CI [0.16, 0.80], $P < 0.01$, $I^2 = 28.6\%$). The higher OKS score was only observed in the short-term (six studies, 440 knees, MD = 0.78, $P < 0.01$) (Table 5). There was no difference after 1 year postoperatively. Other subgroup analyses suggested higher scores in the resurfaced knees in patients who had unilateral TKA (MD = 0.53, $P < 0.01$) and used PS prosthesis (MD = 0.81, $P < 0.01$; Table 6).

The Western Ontario and McMaster Universities Arthritis Index (WOMAC)

Three studies ($n = 248$) reported on the WOMAC scores. The non-resurfacing knees had higher scores in the functional part (MD = −0.19, 95% CI [−0.40, −0.01], $P = 0.05$, $I^2 = 0\%$; Table 5). There was no difference in pain or stiffness parts of WOMAC.

The Knee Injury and Osteoarthritis Outcome Score (KOOS)

The non-resurfacing knees had slightly higher scores in terms of pain (MD = −4.20, $P < 0.01$, $I^2 = 0\%$), symptom (MD = −2.93, $P = 0.01$, $I^2 = 0\%$), and quality of life (MD = −4.98, $P < 0.01$, $I^2 = 0\%$) components. And there was no difference in activity daily living or sports components (Table 5).

Complications

The RRs of complications were not significant except for patellar clunk. Eleven studies ($n = 962$) reported on patellar clunk, and we found that resurface knees were associated with a lower rate of patellar clunk (RR = 0.58, 95% CI [0.38, 0.88], $P = 0.01$, $I^2 = 0\%$; Table 5).

Radiography

Patellar Score

The MD for patellar score favored the resurfaced knees (MD = 1.24, 95% CI [0.67, 1.81], $P < 0.01$, $I^2 = 73.80\%$). Subgroup analysis found that the higher scores in resurfaced knees could be observed up to 5 years (<1 year: 6 studies, 478 knees, MD = 1.06, $Pp = 0.01$, $I^2 = 30.4\%$; 1–5 year: 12 studies, 1145 knees, MD = 1.33, $P < 0.01$, $I^2 = 80.4\%$; Table 5). Due to the high heterogeneity we found, sensitivity analysis was applied *via* omitting each included study and showed stable results. The results favored resurfaced knees in subgroups of unilateral TKA (MD = 1.36, $P < 0.01$) and CR prosthesis (MD = 1.49, $P < 0.01$; Table 6).

Patellar Title Angel, Patellar Displacement, Insall–Salvati Index

Seven studies ($n = 842$) reported patellar title angel, and the MD was insignificant ($P = 0.29$). Four studies ($n = 566$, $p = 0.22$) reported on patellar displacement, and six studies ($n = 788$, $P = 0.39$) reported on Insall–Salvati index. Either result was not significant (Table 5). Since the high heterogeneity, sensitivity analysis was applied *via* omitting each included study and showed stable results.

Clinical Outcome

Surgery Length

Eight studies ($n = 761$) reported on surgery length. Knees with patellar resurfacing had prolonged surgery time (MD = 8.59, 95% CI [5.27, 11.91], $P < 0.01$, $I^2 = 88.80\%$). Sensitivity analysis was performed due to the relatively high heterogeneity and did not change the results.

Blood Loss

The MD of blood loss was found to be not significant (MD = 14.94, 95% CI [−0.63, 30.51], $P = 0.06$, $I^2 = 86.60\%$; Table 5). Sensitivity analysis was performed

TABLE 4 Methodologic quality assessment of included studies (RCT)

Study (first author) and year	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of participants and personnel (performance bias)	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Other bias
Ali 2016	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Aunan 2016	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Bourne 1995, Burnett 2004	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Barrack 1997, 2001, Burnett 2007, 2009	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Johnston 2009, Breeman 2011, Murray 2014	Low risk	Low risk	High risk	Low risk	Low risk	Low risk
Beaupre 2012	Low risk	Low risk	Low risk	Low risk	High risk	Low risk
Campbell 2006	Low risk	Low risk	Low risk	Low risk	High risk	Low risk
Chawla 2019	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Dong 2017	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Deroche 2021	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Eshnazarov 2016	Unclear	Unclear	Unclear	Low risk	Low risk	Low risk
Feller 1996	Low risk	Low risk	Unclear	Unclear	Low risk	Low risk
Ferguson 2014, Ferguson 2015	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Gildone 2005	Unclear	Unclear	Unclear	Low risk	Low risk	Low risk
Huang 2007	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Ha 2019	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Jia 2018	Unclear	Unclear	Unclear	Unclear	Low risk	Low risk
Shoji 1989, Kajino 1997	Low risk	Unclear	Low risk	Unclear	High risk	Low risk
Kordelle 2003	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Kaseb 2018	Low risk	Low risk	High risk	Low risk	Low risk	Low risk
Kaseb 2019	Low risk	Low risk	High risk	Low risk	Low risk	Low risk
Koh 2019	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Liu 2007	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Liu 2012	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Mayman 2003	Unclear	Low risk	Low risk	Low risk	High risk	Low risk
Myles 2006	Low risk	Low risk	Low risk	Low risk	High risk	Low risk
Newman 2000	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Patrtio 1995	Unclear	Unclear	Unclear	Low risk	low risk	Low risk
Rodríguez 2010	Unclear	Low risk	Low risk	Low risk	Low risk	Low risk
Roberts 2015	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Raaij 2020	Unclear	Low risk	High risk	Unclear	Low risk	Low risk
Schroeder-Boersch 1998	Unclear	Unclear	Low risk	Low risk	Low risk	Low risk
Smith 2008	Low risk	Low risk	Low risk	Low risk	High risk	Low risk
Sreehari 2014	High risk	High risk	Unclear	Unclear	Low risk	Low risk
Tabutin 2005	Unclear	Unclear	Unclear	Low risk	Low risk	Low risk
Thieng 2019	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Vukadin 2017	Unclear	Unclear	High risk	Low risk	Low risk	Low risk
Waikakul 2000	low risk	low risk	low risk	low risk	low risk	Low risk
Wood 2002	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Waters 2003	Low risk	Unclear	Low risk	Low risk	Low risk	Low risk
Wang 2017	Unclear	Unclear	High risk	Unclear	Low risk	Low risk
Yang 2013	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk

due to the relatively high heterogeneity and did not change the results.

Range of Motion (ROM)

Twenty-two studies ($n = 2390$) reported knee ROM. The MD for ROM was not significant (MD $= 0.17$, 95% CI [-0.90, 1.23], $P = 0.76$, $I^2 = 42.90\%$).

Mortality

Twenty studies ($n = 3957$) reported on mortality. Moreover, there was no difference between patellar resurfacing and non-resurfacing (RR $= 1.13$, 95% CI [0.78, 1.63], $P = 0.53$, $I^2 = 0\%$; Table 5).

Patient Satisfaction

Twenty-three studies ($n = 2540$) reported on patient satisfaction. There was no difference between patellar resurfacing and non-resurfacing (RR $= 1.03$, 95% CI [0.98, 1.09], $P = 0.19$, $I^2 = 68.2\%$). Sensitivity analysis was performed due to the relatively high heterogeneity and did not change the results.

Patient Preference

We found that the overall patient preference for patellar resurfacing was 160 (36.28%), while patellar non-resurfacing was 150 (34.01%). There was no difference between the

TABLE 5 The pooled results of the meta-analysis

Outcomes	Sample size	MD/RR (95% CI)	*p*-Value	I^2 (%)	Model
Primary outcome					
Revision rates					
Non-patellar revision	4381	0.643 (0.549, 0.754)	<0.0001*	0.00	RM
Patellar revision	2890	0.412 (0.193, 0.881)	0.022*	24.20	RM
Secondary outcomes					
Anterior knee pain	4495	0.720 (0.570, 0.911)	0.006*	69.50	RM
PROMs					
KSS					
KSS (total score)	749	1.867 (−1.267, 5.001)	0.243	0	RM
KSS (clinical score)	4520	0.616 (0.206, 1.027)	0.003*	29.60	RM
KSS (functional score)	4256	1.452 (0.717, 2.187)	<0.0001*	39.30	RM
OKS	4131	0.477 (0.155, 0.799)	0.004*	28.60	RM
WOMAC					
WOMAC (pain)	248	−0.218 (−1.675, 1.239)	0.769	61.40	RM
WOMAC (stiffness)	248	−0.683 (−1.449, 0.083)	0.08	64.40	RM
WOMAC (function)	248	−0.199 (−0.396, −0.003)	0.047*	0.00	RM
KOOS					
KOOS (pain)	606	−4.196 (−6.586, −1.806)	0.001*	0.00	RM
KOOS (symptom)	606	−2.925 (−5.222, −0.627)	0.013*	0.00	RM
KOOS (ADL)	606	−0.577 (−3.639, 2.485)	0.712	22.60	RM
KOOS (sports/rec)	606	−3.620 (−7.502, 0.263)	0.068	6.80	RM
KOOS (QOL)	606	−4.978 (−8.068, −1.888)	0.002*	0.00	RM
Complications					
Patellar crepitus	731	0.876 (0.663, 1.157)	0.35	35.70	RM
Patellar clunk	962	0.582 (0.384, 0.881)	0.01*	0.00	RM
Patellar fracture	678	0.695 (0.110, 4.381)	0.699	0.00	RM
Patellar tendon damage	478	0.252 (0.028, 2.261)	0.218	0.00	RM
Dislocation	2023	1.549 (0.227, 10.549)	0.655	38.60	RM
Subluxation	609	0.906 (0.568, 1.446)	0.679	0.00	RM
Other patellar complications	3967	1.050 (0.844, 1.307)	0.659	0.00	RM
Infection	2540	1.598 (0.905, 2.823)	0.106	0.00	RM
Radiography					
Patellar title angel	842	−0.842 (−2.405, 0.721)	0.291	85.90	RM
Patellar displacement	566	−0.487 (−1.262, 0.289)	0.219	98.50	RM
Insall–Salvati index	788	0.036 (−0.046, 0.118)	0.388	90.20	RM
Patellar score	1623	1.238 (0.668, 1.809)	<0.0001*	73.80	RM
Clinical outcomes					
ROM	2390	0.166 (−0.900, 1.232)	0.76	42.90	RM
Surgery length	761	8.590 (5.271, 11.909)	<0.0001*	88.80	RM
Blood loss	511	14.940 (−0.633, 30.513)	0.06	86.60	RM
Patient satisfaction	2540	1.034 (0.983, 1.088)	0.189	68.20	RM
Mortality	3957	1.126 (0.780, 1.625)	0.526	0.00	RM

Abbreviations: ADL, the activity of daily living; EQ-5D, European quality of life-5 dimensions; KOOS, knee injury, and osteoarthritis outcome score; KSS, knee society scores; OKS, Oxford knee score; PROMs, the patient-reported outcome measures; QOL, quality of life; RM, random effect; ROM, range of motion; RR, risk ratio; WMD, weight mean difference; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.; * Represents a statistical difference.

patient preference of the patellar choice (Supplementary Table 4).

Publication Bias

The funnel plots for publication bias were symmetrical, indicating no publication bias based on the outcome of revision, KSS clinical, KSS functional, and AKP (Fig. 6).

Discussion

Key Findings

This study incorporated all available RCTs and provided reliable results with the largest population. We found statistically significant differences that favored PR in the primary outcome (revision) and secondary outcomes, including AKP, PROMs (KSS clinical score, KSS functional score, OKS), patellar score, and patellar clunk. However, the results of surgery length and KOOS scores favored nonresurfacing. Subgroup analysis provided valuable information. The benefits in revision, KSS clinical, and functional scores were observed for up to 10 years, while a lower rate of AKP was only observed within the first year after surgery. The revision, AKP, and patellar scores favored PR with uni-TKA and CR prosthesis, while clinical and functional scores of KSS favored PR with bi-TKA and PS prosthesis. Patients diagnosed with OA and RA could both benefit from

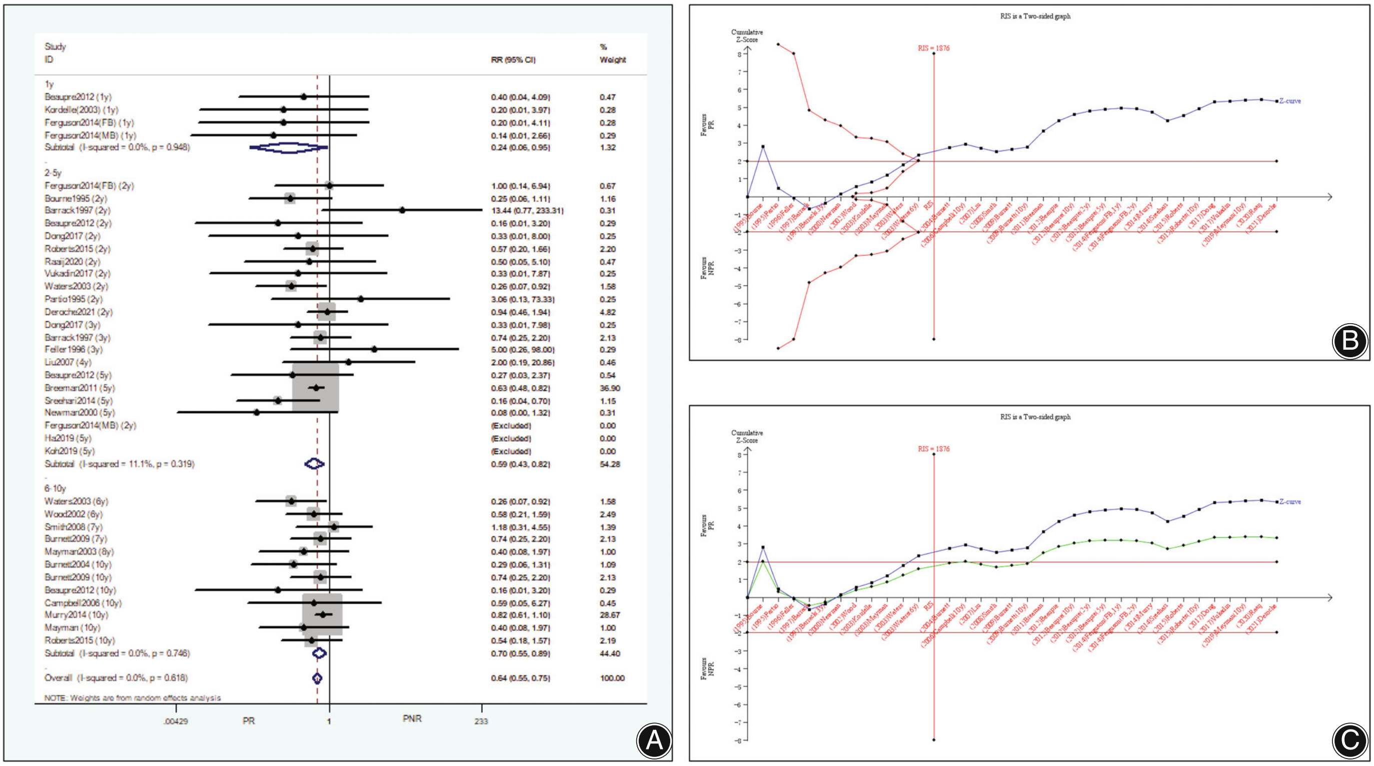

Fig. 2 Effect of patellar resurfacing on revision in included trials. (A) Forest plot of revision in RCTs. (B) Trial sequential analysis of revision in RCTs (adjusted boundaries print). (C) Trial sequential analysis of revision in RCTs (penalized test print)

PR. The quality of evidence by GRADE assessment in the four outcomes was moderate to high. The results of TSA showed that the number of patients needed to confirm the benefits of revision and AKP had reached the TSA boundary for benefit, and KSS clinical reached the futility line with abundant data.

Revisions

The revision was categorized as non-patellar (i.e., due to tibia or femoral-related complications) and patellar revisions (due to patellar-related complications), as referenced in a previous study.[2] Patellar resurfacing was associated with reduced non-patellar and patellar revisions, in line with an investigation in the Netherlands[74] and previous meta-analysis.[2,4–13,75] In our analysis, the number needed to treat (NNT) to prevent one revision was 13 knees, compared to 25 in Teel's study.[5] Our study confirmed a decreased number of patients needed to treat to prevent one revision. Possible reasons were that we included long-term follow-up studies, and the revision was decreased in the long-term. Subgroup analysis also suggested that patellar resurfacing with uni-TKA and CR prosthesis had lower non-patellar revision rates. The prosthetic design plays a role in the development of the tibia and femoral problems. It has been postulated that patellofemoral kinematics are improved by retention of the posterior cruciate ligament and that this improvement is translated into improved kinemics.[76,77] Therefore, the friction between the tibia and femoral was improved and reduced the rate of non-patellar revision. Patients receiving the unilateral TKAs would use the other leg as the primary source of daily activity and thus reduce the possibility of complications required revision.

Anterior Knee Pain

Studies demonstrated that the anterior knee pain rates ranged from 0% to 30.1% with patellar resurfacing and 4.35% to 47% with patellar nonresurfacing. In our study, the incidence of anterior knee pain was decreased in the patellar resurfacing group with an RR of 0.72. The result was consistent with previous studies.[5,7,12–17] In subgroup analysis, the difference disappeared after 1 year, indicating the superiority is short-lived. One explanation was that anterior knee pain is dynamic, and most of them happened in 5 to 7 years postoperatively.[49,59] Even patellar resurfacing relieved the preoperative anterior knee pain, the new on-set pain after surgery cannot be avoided. The second possible explanation was that reasons that lead to anterior knee pain are multiple, such as muscle imbalances, dynamic valgus, patellar-femoral compartment overstuffing, or rotational alignment mistakes.

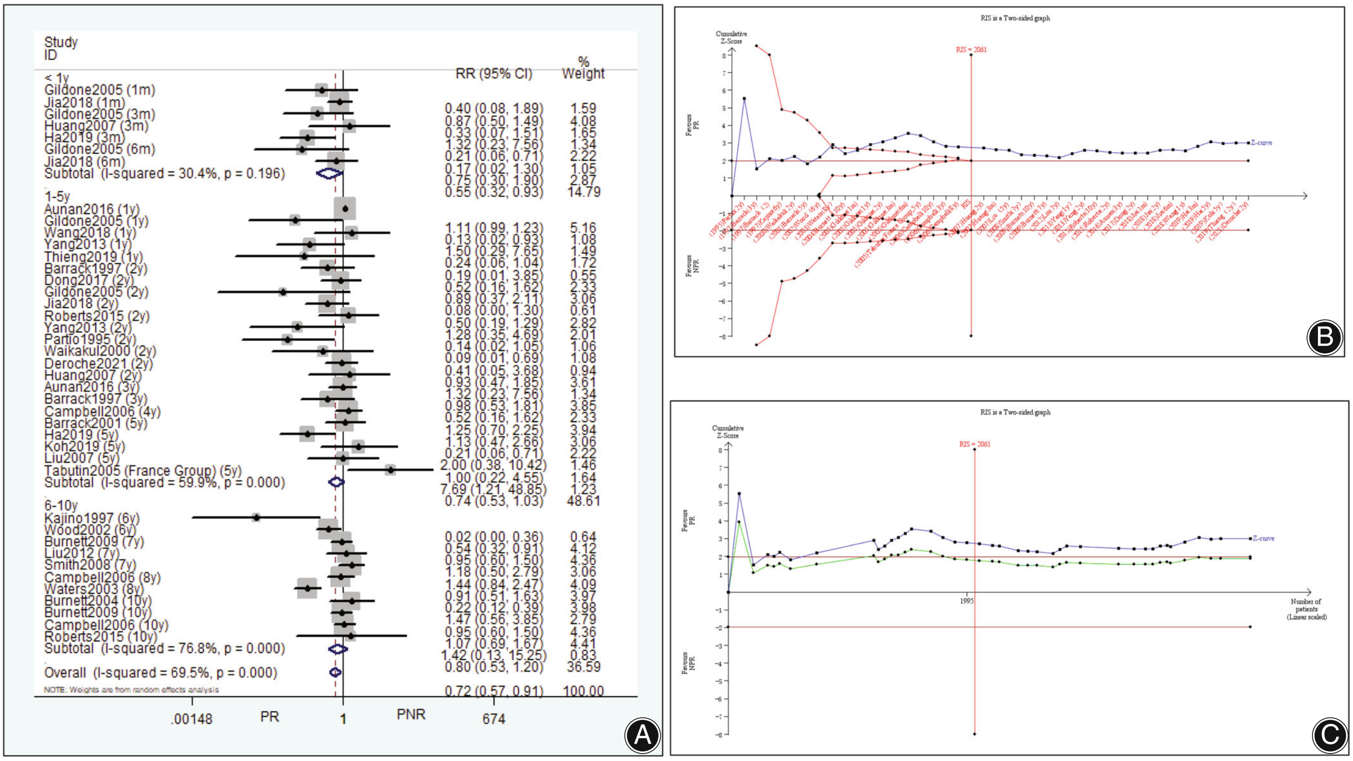

Fig. 3 Effect of patellar resurfacing on KSS clinical component in included trials. (A) Forest plot of KSS clinical component in RCTs. (B) Trial sequential analysis of KSS clinical component in RCTs (adjusted boundaries print). (C) Trial sequential analysis of KSS clinical component in RCTs (penalized test print)

An isolated patellar resurfacing was unable to solve all the problems.

Furthermore, patellar resurfacing with uni-TKA (RR = 0.6) and CR prosthesis (RR = 0.6) strengthened the benefit. Both OA and RA patients had reduced AKP after patellar resurfacing. Possible reasons are that the trauma after uni-TKA was less than that of bi-TKA, which may decrease the knee pain. Also, patients improved by retaining the posterior cruciate ligament when using CR prosthesis for PR, thus providing pain relief.[20] Of note, these results should be cautiously considered since there was no consensus in the definition of anterior knee pain, with some researchers believing that the VAS score above five was defined as anterior knee pain, some agree with the number of eight, while the others take patients complaint of pain as anterior knee pain.

Patient-Reported Outcome Measures (PROMs)

The KSS total score was similar between patellar resurfacing and nonresurfacing, while the clinical (MD = 0.61) and functional parts (MD = 1.45) favored patellar resurfacing, with marginally and not clinically meaningful benefit. The minimum clinically important difference (MCID) for KSS clinical score was 5.3 to 5.9 points, and for KSS functional score was 6.1 to 6.4 points. Our results were consistent with previous meta-analyses.[5–7] Subgroup analysis found the benefit for KSS clinical score lasted from 1 to 10 years postoperatively while for functional score it lasted up to 5 years. The lack of long-term benefit in the function component of KSS may be related to patients' whole diminishing health status. The results also suggested that bi-TKA and PS prosthesis would strengthen resurfacing benefits. Possible reasons are that patients receiving bi-TKA are usually stronger and younger than those receiving uni-TKA because of surgeons' preference.[77] Studies reported that PS design could achieve better postoperative knee range of motion results than CR prosthesis.[78,79] However, there was an ongoing discussion in the selection of CR or PS prosthesis, which may not be in the scope of our study. Though we would recommend CR prosthesis in light of its benefit in reducing revision and pain, the surgeons should have a clear idea of the technical differences between CR and PS TKAs and choose based on patients' conditions.

Some studies reported the scores of OKS but found no difference.[2,3,5] However, in our study, OKS scores (MD = 0.48) supported patellar resurfacing though had no clinical importance (MCID for OKS: >2 points).[40] On the contrary, synthesized data supported patellar nonresurfacing concerning KOOS pain, stiffness, quality of life. Our results were contrary to a previous meta-analysis.[2] Two new large

TABLE 6 Subgroup analysis of outcomes (enrolled more than 10 trials)

Variables (years)	No of trials/ patients	Follow-up Relative risk (95% CI)	P-Value*	I^2 (%)	Uni-TKA/bi-TKA	Relative risk (95% CI)	p-Value*	I^2 (%)	CR/PS	Relative risk (95% CI)	p-Value*	I^2 (%)	OA/RA	Relative risk (95% CI)	p-Value*	I^2 (%)
KSS (total score)																
<1	3 (219)	2.181 (−1.961, 6.323)	0.302	0	Uni	1.435 (−3.827, 6.698)	0.593	0	CR	3.062 (−5.209, 11.332)	0.468	0	OA	1.867 (−1.267, 5.001)	0.243	0
1–5	5 (466)	−0.442 (−4.100, 3.215)	0.813	0	Bi	−0.019 (−9.616, 9.578)	0.997	0	PS	1.667 (−1.719, 5.053)	0.335	0	RA	N/A		
6–10	1 (64)	−5.802 (−14.825, 3.222)	0.208	0	Mix	2.525 (−1.745, 6.795)	0.246	0	Mix	N/A			Mix	N/A		
KSS (clinical score)																
<1	16 (1047)	0.475 (−0.932, 1.882)	0.508	59.70	Uni	0.010 (−0.882, 0.902)	0.983	55.60	CR	0.006 (−1.187, 1.200)	0.991	67	OA	0.468 (0.003, 0.932)	0.048†	31
2–5	37 (4084)	0.763 (0.431, 1.095)	<0.0001†	4.20	Bi	1.031 (0.596, 1.466)	<0.0001†	0.00	PS	0.731 (0.273, 1.189)	0.002†	0	RA	N/A		
6–10	9 (1389)	1.567 (0.505, 2.629)	0.004†	0.00	Mix	0.998 (0.290, 1.706)	0.006†	17.20	Mix	0.904 (0.272, 1.535)	0.005†	16	Mix	1.279 (0.621, 1.936)	<0.0001†	0
KSS (functional score)																
<1	14 (894)	1.119 (0.063, 2.175)	0.038†	0.00	Uni	0.855 (−0.539, 2.248)	0.229	52.50	CR	1.215 (−1.590, 4.019)	0.396	33.30	OA	1.273 (0.129, 2.416)	0.029†	44.30
2–5	36 (4189)	1.467 (0.545, 2.388)	0.002†	51.60	Bi	1.719 (1.214, 2.224)	<0.0001†	0.00	PS	1.777 (1.119, 2.435)	<0.0001†	29.50	RA	N/A		
6–10	10 (1173)	1.619 (−1.222, 4.459)	0.264	26.70	Mix	2.501 (0.019, 4.984)	0.048†	43.50	Mix	−3.017 (−7.192, 1.157)	0.157	55.10	Mix	1.764 (1.252, 2.276)	<0.0001†	0
AKP																
<1	7 (515)	0.546 (0.321, 0.931)	0.026†	30.40	Uni	0.600 (0.372, 0.969)	0.037†	56.90	CR	0.600 (0.405, 0.890)	0.011†	75.20	OA	0.786 (0.641, 0.964)	0.02†	52.60
2–5	23 (2434)	0.736 (0.527, 1.027)	0.072	59.90	Bi	0.920 (0.677, 1.251)	0.596	37.30	PS	1.036 (0.848, 1.266)	0.731	0.20	RA	0.023 (0.001, 0.365)	0.007†	0
6–10	11 (1543)	0.797 (0.527, 1.204)	0.28	76.80	Mix	0.680 (0.426, 1.086)	0.107	83.40	Mix	0.608 (0.284, 1.305)	0.202	75.10	Mix	0.562 (0.085, 3.720)	0.551	95.70
Revision																
<1	4 (440)	0.238 (0.060, 0.947)	0.042†	0.00	Uni	0.592 (0.465, 0.753)	<0.0001†	0.00	CR	0.558 (0.392, 0.793)	0.001†	0.00	OA	0.547 (0.408, 0.732)	<0.0001†	0.00
2–5	22 (4426)	0.592 (0.429, 0.817)	0.001†	11.10	Bi	0.883 (0.472, 1.650)	0.696	0.00	PS	0.796 (0.467, 1.358)	0.402	0.00	RA	N/A		
6–10	12 (3515)	0.702 (0.553, 0.891)	0.004†	0.00	Mix	0.664 (0.530, 0.831)	<0.0001†	0.00	Mix	0.515 (0.333, 0.796)	0.003†	51.80	Mix	0.661 (0.437, 1.000)	0.05†	55.00
Oxford knee score																
<1	5 (1995)	0.787 (0.304, 1.270)	0.001†	0.00	Uni	0.531 (0.229, 0.832)	0.001†	19.40	CR	−1.500 (−3.089, 0.089)	0.064	0.00	OA	0.925 (0.053, 1.797)	0.038†	61.80
2–5	14 (9537)	0.511 (−0.074, 1.096)	0.087	54.50	Bi	N/A			PS	0.819 (0.310, 1.327)	0.002†	43.40	RA	N/A		
6–10	5 (4884)	0.222 (−0.378, 0.822)	0.469	0.00	Mix	−1.500 (−3.089, 0.089)	0.064	0.00	Mix	0.323 (−0.075, 0.722)	0.112	0.00	Mix	0.434 (0.127, 0.741)	0.004†	0.00

TABLE 6 Continued

		Follow-up				Uni-TKA/bi-TKA				CR/PS				OA/RA		
Variables (years)	No of trials/ patients	Relative risk (95% CI)	*P*-Value*	I^2 (%)		Relative risk (95% CI)	*p*-Value*	I^2 (%)		Relative risk (95% CI)	*p*-Value*	I^2 (%)		Relative risk (95% CI)	*p*-Value*	I^2 (%)
Patellar score																
<1	6 (478)	1.061 (0.405, 1.717)	0.002†	30.40	Uni	1.363 (0.286, 2.440)	0.013†	75.80	CR	1.498 (0.882, 2.114)	<0.0001†	65.00	OA	N/A		
2–5	12 (1145)	1.335 (0.576, 2.134)	0.001†	80.40	Bi	−0.176 (−1.244, 0.891)	0.746	27.80	PS	1.259 (0.297, 2.220)	0.01†	77.20	RA	N/A		
6–10					Mix	1.498 (0.882, 2.114)	<0.0001†	65.00	Mix	N/A			Mix	N/A		
ROM																
<1	4 (290)	1.320 (−1.021, 3.662)	0.269	42.50	Uni	0.444 (−1.225, 2.114)	0.602	57.50	CR	−0.706 (−2.498, 1.086)	0.44	0.00	OA	0.166 (−0.900, 1.232)	0.76	42.90
2–5	13 (1611)	0.028 (−1.656, 1.713)	0.974	52.80	Bi	−2.265 (−5.438, 0.909)	0.162	0.00	PS	−0.376 (−1.646, 0.894)	0.562	26.30	RA	N/A		
6–10	5 (489)	−1.370 (−3.730, 0.990)	0.255	0.00	Mix	0.616 (−0.806, 2.037)	0.396	6.10	Mix	2.835 (0.406, 5.264)	0.022†	42.70	Mix	N/A		
Mortality																
<1	5 (742)	1.147 (0.479, 2.748)	0.759	0.00	Uni	0.960 (0.478, 1.926)	0.908	0.00	CR	1.261 (0.640, 2.487)	0.502	0.00	OA	1.010 (0.682, 1.494)	0.962	0.00
2–5	9 (1165)	1.224 (0.680, 2.206)	0.5	0.00	Bi	1.353 (0.452, 4.056)	0.589	56.00	PS	1.215 (0.712, 2.072)	0.476	0.00	RA	N/A		
6–10	6 (2050)	1.037 (0.595, 1.808)	0.897	0.00	Mix	1.252 (0.693, 2.263)	0.457	0.00	Mix	0.841 (0.396, 1.788)	0.653	0.00	Mix	2.425 (0.858, 6.858)	0.095	0.00
Patient satisfaction																
<1	4 (314)	1.398 (0.770, 2.537)	0.271	91	Uni	1.080 (0.861, 1.354)	0.505	73.10	CR	1.083 (0.974, 1.206)	0.142	82.00	OA	1.039 (0.981, 1.101)	0.194	72.20
2–5	11 (1058)	1.039 (0.965, 1.119)	0.308	69	Bi	1.123 (0.924, 1.365)	0.245	86.00	PS	0.970 (0.918, 1.024)	0.273	0.00	RA	N/A		
6–10	8 (1168)	1.006 (0.947, 1.069)	0.839	54	Mix	1.021 (0.970, 1.075)	0.426	62.80	Mix	1.042 (0.963, 1.128)	0.306	61.80	Mix	1.035 (0.964, 1.110)	0.343	0.00

Abbreviations: AKP, anterior knee pain; CR, cruciate retaining; KSS, knee society scores; OA, osteoarthritis; PS, posterior substitute; RA, rheumatoid arthritis; ROM, range of motion.; † Represents a statistical difference, $p < 0.05$.

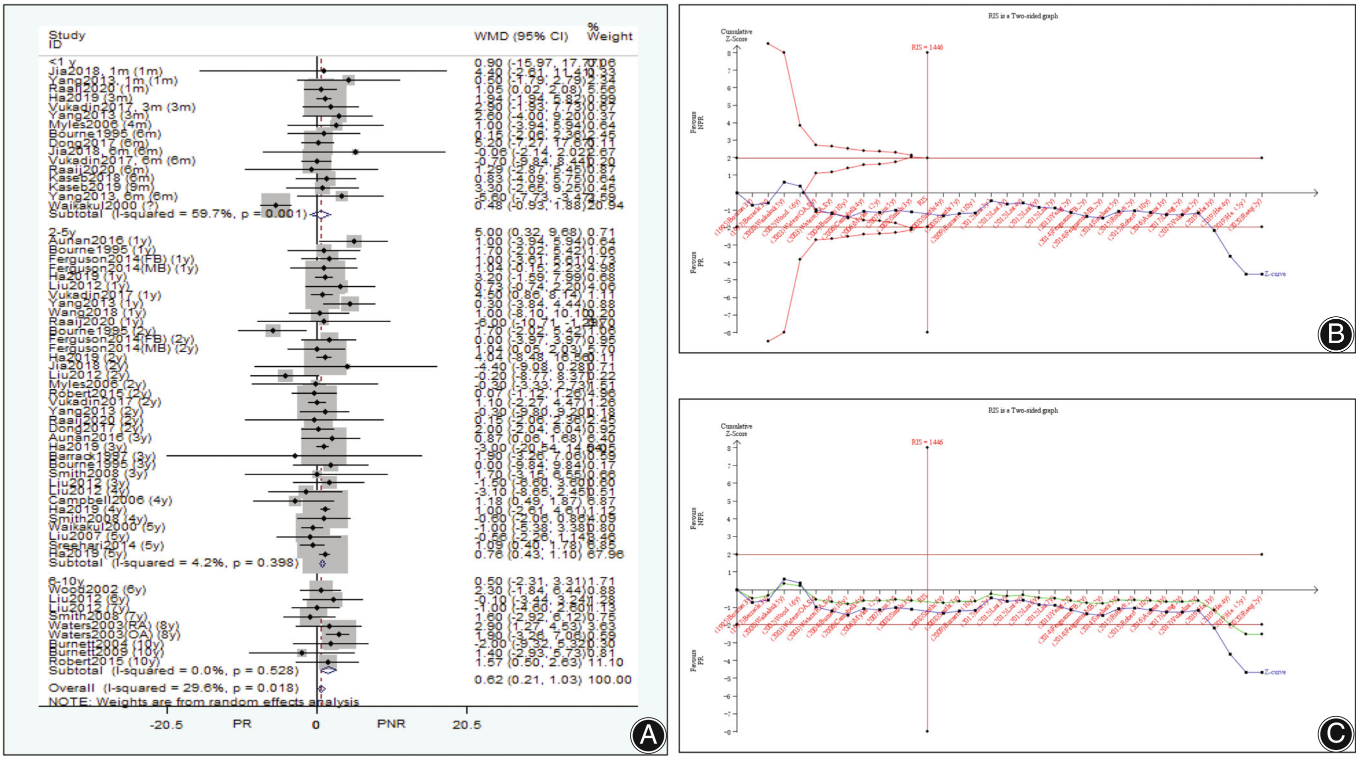

Fig. 4 Forest plot of the functional component of KSS in the meta-analysis comparing patellar resurfacing versus patellar non-resurfacing of TKA

RCTs[18,20] enrolled in our study providing new information may explain the difference. Similarly, the difference in KOOS also lacked clinical importance (MCID for KOOS: 8 to 10 points). The conflict results of PROMs may be due to the short follow-up periods (3 months to 6 years) and limited data.[18,20,29,30,50,51] The difference should be considered carefully, and future prospective studies with large populations should be expected.

Complications

Patellar resurfacing used to be criticized because it was associated with more complications than nonresurfacing, such as aseptic loosening, patella fractures, or osteonecrosis. However, it usually takes a long period to observe these complications, and most previous studies only provided data regarding complications that occurred in the short-term.[29,45] Our study reported various complications (i.e., patellar crepitus, patellar clunk, patellar fracture, patellar tendon damage, dislocation, subluxation, other patellar complications, and infection) with sufficient data from long-term reports. We found that the occurrence of patellar clunk was reduced in the patellar resurfacing group. Our analysis was in line with previous studies.[3,5] The well-tracking of patellar in the resurfacing group may explain this difference. With the advance of implant designs and surgical techniques, most complications were denied, confirming that both resurfacing and nonresurfacing are safe.

Others

We reported four metrics in the radiography area, including patellar tilt angle, patellar displacement, Insall–Salvati index, patellar scores. The synthesized results indicated that the patellar resurfacing was associated with a higher patellar score (MD = 1.24). The only benefit for non-resurfaced patellar was that non-resurfaced patellar had a shorter surgery length (MD = 8.59). However, the reduced surgery length did not reduce the infection risk. Therefore, the clinical significance was not significant. There was no difference in the other outcomes such as blood loss, patient satisfaction, mortality, and patient preference.

The strengths of this study include: (i) prospective design with the largest population; (ii) sufficient number of long-term reports; (iii) explicit eligibility criteria; (vi) a comprehensive search of the relevant literature; (v) assessment of eligibility and risk of bias in duplicate; (vi) objective and subjective outcomes were included; (vii) and exploration of possible subgroup effects related to the duration of follow-up, surgery (unilateral or bilateral), the prosthesis (CR or PS), and diagnosis (OA or RA). Also, we conducted an analysis of PROMs that related the results to the MICD; and

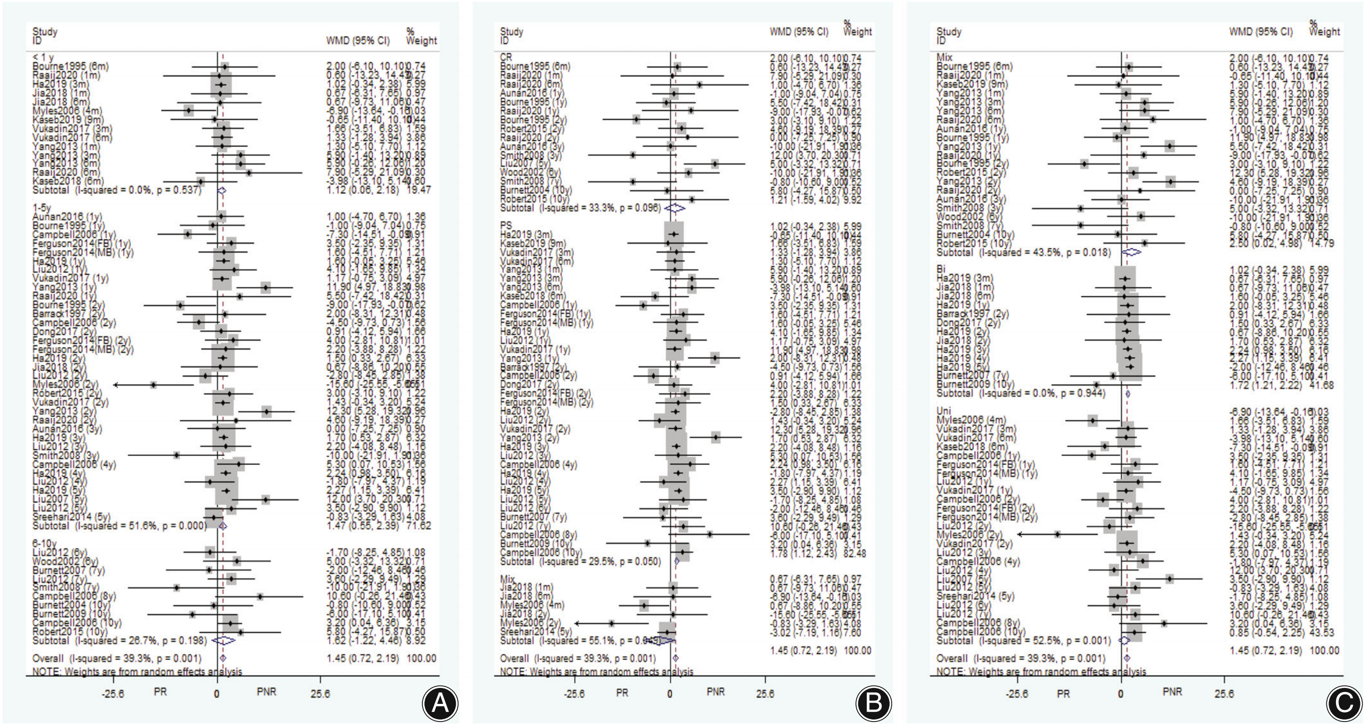

Fig. 5 Effect of patellar non-resurfacing on anterior knee pain in included trials. A. Forest plot of anterior knee pain in RCTs. B. Trial sequential analysis of anterior knee pain in RCTs (adjusted boundaries print). C. Trial sequential analysis of anterior knee pain in RCTs (penalized test print)

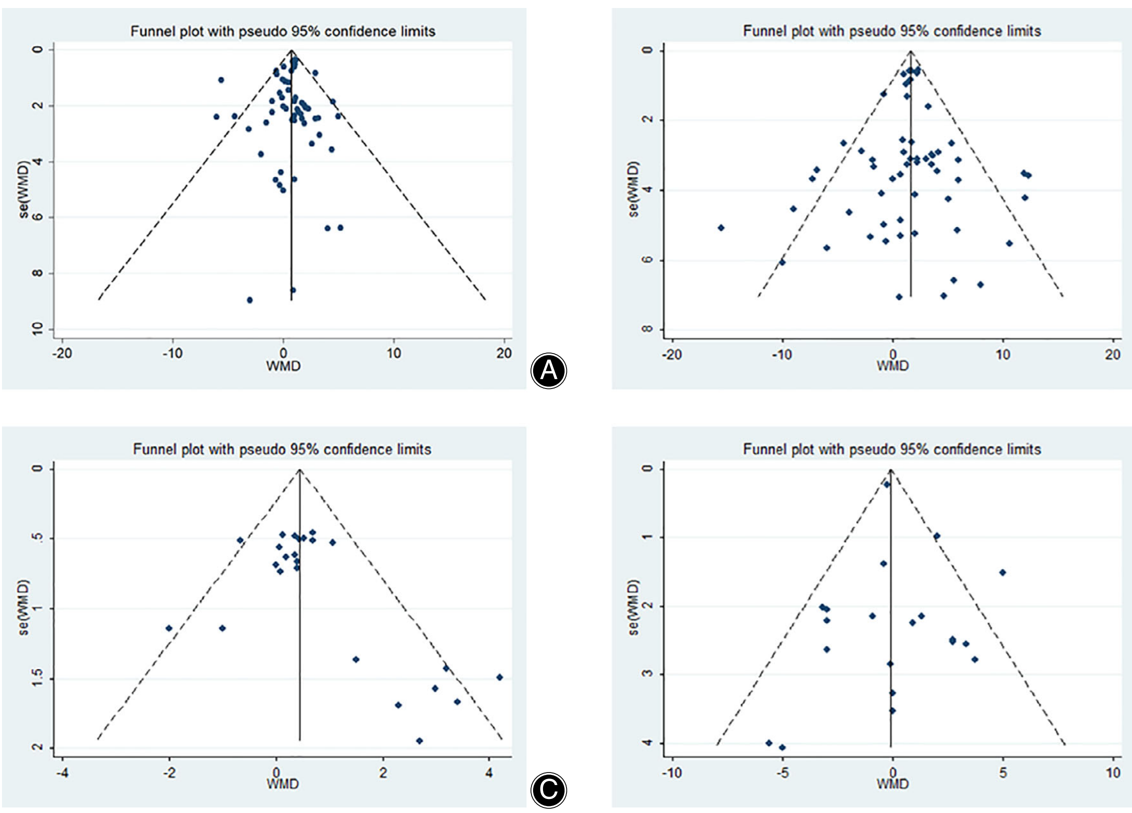

Fig. 6 Funnel plots

(viii) TSA analysis and GRADE system were applied for evidence rating.

The limitations of this study include: (i) limited data for the assessment of KOOS and WOMAC; (ii) confounding factors may have reduced homogeneity of results, such as implant design, different surgeons, approach and others; and (iii) and several long-term studies had high attrition bias.

Conclusions

The clear relationship is that patellar resurfacing reduces revisions, anterior knee pain, and patellar clunk. The results of PROMs lack clinical importance, with evidenced higher KSS clinical scores, KSS functional scores, OKS with patellar resurfacing. Patellar resurfacing with uni-TKA and CR prosthesis could reduce the rates of AKP and revision. It will be interesting to compare the initial cost with the revision cost when required and cost-utility analysis with long-term results in future studies.

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Author Contribution

TXM，HY conceived the methods of the study, performed the database search, the article selection, and data extraction processes, performed the statistical analysis, and drafted the manuscript. PS and LL conceived the methods of the study, performed the database search, the article selection, and data extraction processes, and drafted the manuscript. SY, CJJ, ZZK conceived the methods of the study, helped with the data extraction process, and drafted the manuscript. SY and CCL helped to draft the manuscript. All authors read and approved the manuscript.

Supporting Information

Additional Supporting Information may be found in the online version of this article on the publisher's web-site:

Supplement Table 1: Methodologic quality assessment of included studies (RCT)
Supplement Table 2: The pooled results of the meta-analysis
Supplement Table 3: Subgroup analysis of outcomes (enrolled more than 10 trials)
Supplement Table4: Patient preference of patellar resurfacing and patellar non-resurfacing
Supplement Table 5: GRADE Assessment
Supplement Table 6: Conclusions and follow-up duration of included studies

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