



Robotic-assisted patellofemoral arthroplasty shows superior functional outcomes and lower revision rates compared to conventional technique: a systematic review and meta-analysis

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Abstract

Introduction : Patello-femoral osteoarthritis is a degenerative condition causing anterior knee pain, stiffness, and functional impairment due to cartilage degeneration in the patello-femoral compartment. This systematic review summarises the clinical and functional outcomes of robotic-assisted patello-femoral arthroplasty (RA-PFJA), focusing on pain relief and complication rates, and includes a meta-analysis of reoperation and revision rates from comparative studies between RA-PFJA and conventional PFJA.

Materials and methods A meta-analysis was performed for revision and reoperation rates, while other outcomes were summarised descriptively. This research was conducted across multiple databases according to the Cochrane Handbook and PRISMA guidelines. Eight studies met the inclusion criteria. Outcomes assessed included Oxford Knee Score (OKS), Kujala score, Knee Society Score (KSS), visual analogue scale (VAS), length of hospital stay (LOS), complication, revision, and reoperation rates.

Results Eight studies with a total of 992 patients treated with RA-PFJA were included (641 with Mako, 166 with Navio, 175 with unspecified systems). The mean follow-up was 47.5 ± 29.4 months. RA-PFJA showed excellent final function (Kujala: 87.4 ± 14.1 ; OKS: 39.6 ± 5.4 ; KSS: 81.0 ± 14.2) and significant pain reduction ($p < 0.001$). Compared to conventional PFJA, RA-PFJA had a lower overall complication rate (15% vs. 30%), lower reoperation rate (6.3% vs. 8.6%; OR 0.67; $p = 0.02$), lower revision rate for implant-related causes (0.7% vs. 1.9%; OR 0.32; $p = 0.01$), and shorter LOS (mean difference: -0.34 days; $p = 0.01$).

Conclusion RA-PFJA offers excellent functional outcomes, effective pain relief, and lower revision and complication rates at short to mid-term follow-up. While promising, further high-quality studies are needed to assess long-term results and cost-effectiveness. As robotic systems become more widespread, continued innovation and comparative research will be critical to define their role in orthopaedic surgery.

Keywords Robotic knee arthroplasty · Robotic-assisted arthroplasty · Patella-femoral osteoarthritis · PROM · Review.

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Introduction

Patello-femoral osteoarthritis (PFOA) is a degenerative condition characterised by cartilage degeneration in the patello-femoral (PF) compartment of the knee, resulting in anterior knee pain, stiffness and functional impairment [1, 2]. This condition is prevalent among middle-aged and elderly individuals, with isolated PFOA reported in approximately 9% of people over 40 years of age. The prevalence is notably higher in women, often linked to subtle PF maltracking, malalignment, trochlear dysplasia, as well as underlying anatomical differences in knee biomechanics [3]. Trochlear dysplasia is present in 16% of patients suffering from anterior knee pain [4] and radiographic evidence of PFOA is found in 17–34% of women and 18–19% of men aged 55 years or older, further highlighting its impact in ageing populations [2].

Despite its prevalence, PFOA remains a challenging condition to manage due to its multifactorial aetiology and the limited regenerative capacity of articular cartilage. Factors contributing to disease progression include valgus knee alignment, trochlear or patellar dysplasia, tibial malrotation, and quadriceps muscle imbalance, all of which can exacerbate PF joint wear and instability [5]. These biomechanical abnormalities influence disease severity and often dictate treatment approaches [2, 6].

While conservative management, including bracing, physical therapy and intra-articular injections, can provide symptom relief, surgical intervention is often required for advanced PFOA [6]. Total knee arthroplasty (TKA) has traditionally been the standard surgical treatment for knee OA; however, for patients with isolated PFOA and preserved tibiofemoral joint integrity, patellofemoral joint arthroplasty (PFJA) presents a more conservative alternative [7–9]. Several comparative studies [7–9] indicate that PFJA may offer comparable or even superior outcomes to TKA, particularly for younger, more active patients preserving native knee ligaments and biomechanics, offering potential advantages in maintaining natural joint kinematics. However, the patellar malalignment, instability, and the high revision rates (from 14 to 30%) reported in the literature [10, 11] raise concerns and limit its widespread adoption [12].

To address these challenges, robotic-assisted patellofemoral joint arthroplasty (RA-PFJA) has been developed as a means of enhancing surgical precision, optimising implant positioning, and improving overall outcomes. Modern robotic platforms such as the MAKO [13] and NAVIO systems [14, 15] allow for patient-specific surgical planning, enabling precise bone preparation, component placement, and soft tissue balancing, which may reduce complications and improve implant longevity [16]. However, despite the growing adoption of robotic-assisted techniques in knee

surgery, evidence on their clinical efficacy compared to conventional PFJA remains scarce, with only small case series and short-term follow-ups currently available. This gap underscores the need for systematic evaluation of RA-PFJA outcomes to clarify its true clinical and functional advantages.

This systematic review aims to summarise the clinical and functional outcomes of RA-PFJA, focusing on pain relief, patient satisfaction, and complication rates. The secondary aim of this systematic review is to compare and meta-analyse the reoperation rate and revision rate of comparative studies including RA-PFJA and conventional PFJA.

Materials and methods

This research has been submitted and registered to the International Prospective Register of systematic reviews, PROSPERO (CRD42024602195).

A systematic review was conducted following the guidelines of the Cochrane Handbook for Systematic Reviews of Interventions and the PRISMA guidelines [17] (Fig. 1).

A comprehensive search was performed across multiple databases, including the Cochrane Central Register of Controlled Trials (CENTRAL), MEDLINE/PubMed, Embase, Scopus, Science Citation Index Expanded (Web of Science), ScienceDirect, CINAHL, and LILACS, covering the period from January 1st, 2015, to July 1st, 2025.

The search strategy combined terms and keywords related to “patellofemoral osteoarthritis,” “robotic-assisted surgery,” and “patellofemoral arthroplasty.” The complete search strategy for each database and the detailed PICOS criteria are reported in Appendix 1.

The selection process was based on the participants, intervention, control, outcome, and study design (PICOS). After excluding the duplicates, two reviewers (G.D., M.A.M.), independently screened the title and abstract of each identified article resulting from the primary electronic search. The selected publications were then subjected to a full-text analysis to determine their final inclusion, discrepancies resolved by a third reviewer (G.P.).

The level of evidence of included research studies was classified with the adjusted Oxford Centre For Evidence-Based Medicine 2011 Levels of Evidence [18]. The quality of the studies was defined using the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) system [19]. After the evidence was collected and summarized, the GRADE system provided explicit criteria for rating the quality of evidence that includes study design, risk of bias, imprecision, inconsistency and indirectness (Table 1).

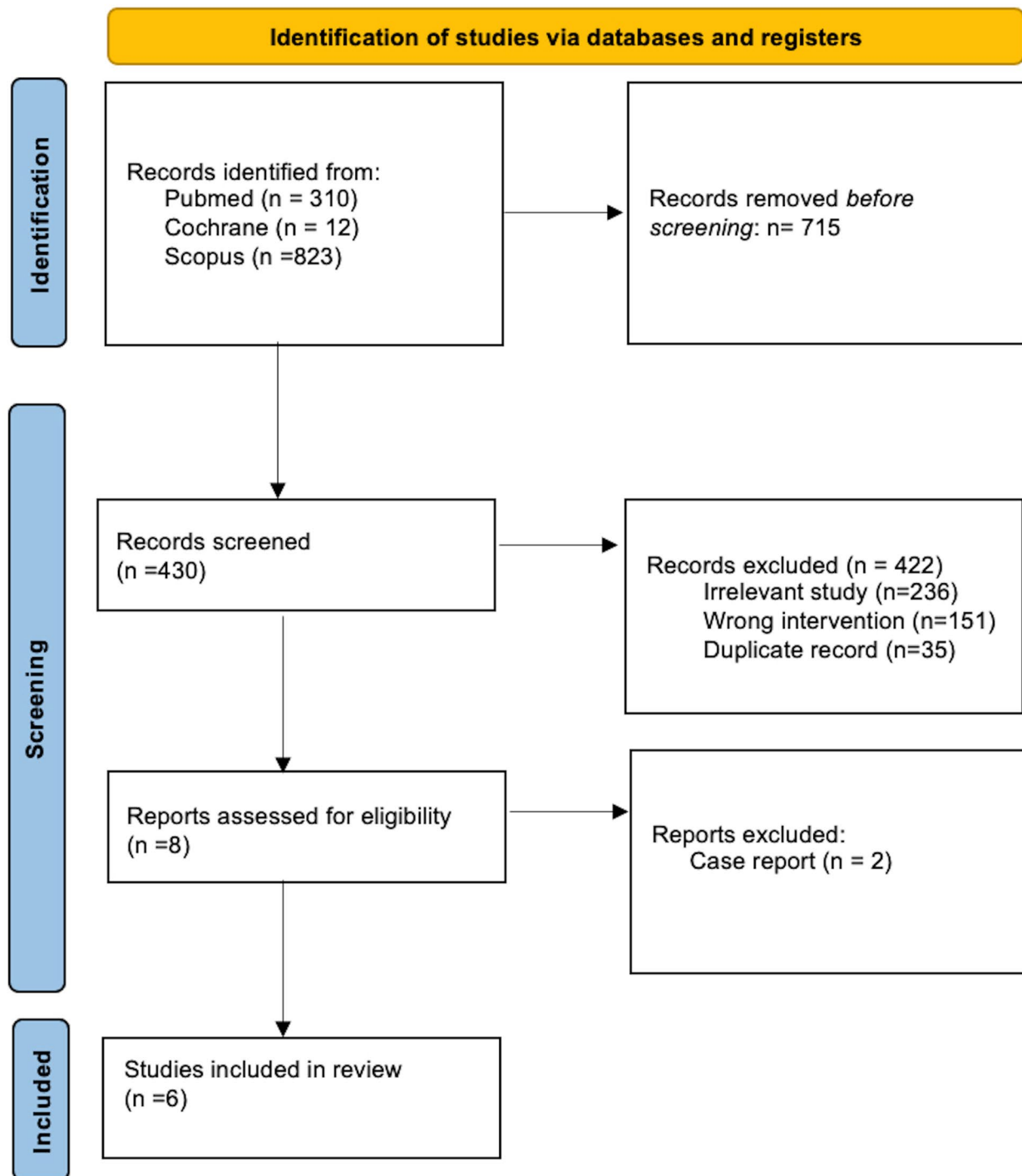


Fig. 1 PRISMA flow diagram of selection process for the included articles

The inclusion criteria were Level I to IV studies assessing patients with PFOA treated with RA-PFJA using either the Mako or NAVIO surgical systems. Eligible studies had to report clinical outcomes such as pain scores, functional assessments, complication rates, or implant survivorship.

Exclusion criteria included Level V studies, case reports, narrative reviews, studies without outcomes data, and those focusing only on conventional PFJA interventions.

Outcomes measured are represented by Oxford Knee Score (OKS) [20], Kujala score [21], Knee Society Score (KSS) [22], visual analogue scale (VAS) for pain [23],

Table 1 GRADE evaluation for included studies, abbreviations: Y=YES; N=NO

Author	Apriori Grade	Risk of bias	Inconsistency of results	Imprecision	Reporting bias	Final grade
Turktas 2015	High	Y	N	N	Y	Low
Selvertnam 2020	High	Y	N	N	Y	Low
Batailler 2023	High	Y	N	N	Y	Moderate
Katzman 2023	High	Y	N	N	Y	Low
Pacchiarotti 2024	High	Y	N	N	Y	Low
Noyes 2024	High	Y	N	N	Y	Low
Ziedas 2025	High	Y	N	N	Y	Moderate
Leie 2025	High	Y	N	N	Y	Moderate

Table 2 General characteristics of the included studies

Study	Year	Country	Study design	Level of evidence	Patients	Mean age at surgery (years±SD)	Female/Male ratio	Mean Follow up (months±SD)	Lost at follow-up
<i>Turktas et al.</i>	2015	Turkey	Retrospective case series	3	29	66.4±11.5	19/10	15.9±5.75	0
<i>Selvaratnam et al.</i>	2020	United Kingdom	Prospective case series	3	23	66.5±12	17/6	30±3.25	0
<i>Batailler et al.</i>	2023	France	Retrospective case-control	3	59 robotic 17 non robotic	60.55±11.9	48/11	40.9±14.3	0
<i>Katzman et al.</i>	2023	Germany	Retrospective case-control	3	94 robotic 90 non robotic	56.4±13.2	70/24	55.2±4.35	0
<i>Pacchiarotti et al.</i>	2024	Italy	Prospective case series	4	18	55.4±14.4	NR	42±9	0
<i>Noyes et al.</i>	2024	United States	Prospective case series	4	44	37.2±7.25	32/12	63.6±21	1
<i>Ziedas et al.</i>	2025	United States	Retrospective case-control	3	56 robotic 19 non robotic	53.0±12.9	59/16	108±0	0
<i>Leie et al.</i>	2025	Australia	Retrospective case-control	3	669 robotic 1481 non robotic	57.8±11.7	151/518	24±15 (robotic) 48±24	0

SD, Standard Deviation

satisfaction rate, complication rate, revision rate and reoperation rate.

Data extraction was performed using a form collecting study characteristics, patient demographics, surgical details, and outcome measures (Tables 2 and 3).

The risk of bias was assessed using the Cochrane Risk of Bias tool, the Risk of Bias in Non-Randomised Studies (ROBINS-I) [24] (Fig. 2).

Data of comparative studies were collected to perform a meta-analysis of outcome measures of conventional PFJA and RA-PFJA.

Statistical analysis

All analyses were completed with Review Manager 5.4.1 software (Cochrane Collaboration, Oxford, UK) and IBM SPSS Statistics version 26.0 (IBM Corp., Armonk, NY, USA) and a p-value funnel plot was used to assess the existence of publication bias for the primary outcome measure (reoperation rate).

For each included study, weighted means, weighted standard deviations, weighted mean differences (MD) and 95% CI were calculated for continuous outcomes, while odds ratios (OR) and 95% CI were calculated for dichotomous outcomes. Statistical heterogeneity among the studies was assessed using the χ^2 test and I^2 . A fixed-effect model was applied when $I^2 < 40\%$, and a random-effect model when $I^2 \geq 40\%$. A p-value of less than 0.05 was considered statistically significant.

Results

A total of eight studies, including 992 patients treated with RA-PFJA (641 operated with the Mako Surgical System, 166 with the Navio Surgical System, and 175 with an unspecified system), met the inclusion criteria [16, 25–31].

The mean age at surgery was 56.7 ± 14.8 years, with an average follow-up of 47.5 ± 29.4 months.

Table 3 Detailed description of the included studies.

Study	Outcomes	Inclusion criteria	Exclusion criteria	Implant design and Robotic system	Pre-operative imaging technique	Surgical Technique
<i>Turktas et al.</i>	OKS and UCLA for patient activity level ratings, VAS for pain, KSS, complications, implant position and rotation	PFOA; PFOA and medial or lateral tibiofemoral compartment osteoarthritis; UKOA; anterior knee pain when getting up from a seated position and going up or downstairs.	NR	NR	X-ray (weight-bearing anteroposterior, lateral and sunrise view) and CT scan	Pre-operative CT scans were used for planning and registering the surgical site. During the surgery, a 3D model of the knee was created. The femur was registered first, with cartilage levels marked for smooth transitions. Implant positioning was adjusted on the computer to ensure optimal placement. A 12-cm mid-patellar incision was made, and the patellar surface was cut with an oscillating saw. The trochlear area, femoral condyle, and tibial plateau were shaped using a high-speed burr on the robotic arm. Polyethylene implants were used for the patella and tibia, while chrome-cobalt implants were used for the femur, secured with methacrylate-based bone cement. Patients with patellar maltracking received lateral release. Post-surgery, patients could fully bear weight the following day and started physical therapy two weeks later, typically lasting six weeks (with a range of two to 20 weeks).
<i>Selvaratnam et al.</i>	ROM (flexion/extension, rotation, varus/valgus), OKS, complications, satisfaction rate	MAKO PFJ replacement with a minimum 2 years follow up	NR	Restoris© MCK Patellofemoral System with MAKO Robotic Arm	X-ray and CT scan	Preoperative planning using CT scans and X-rays was performed according to the Mako protocol, allowing for three-dimensional assessment. The largest trochlear component without medial-lateral overhang was selected, with its distal tip aligned at or posterior to Blumensaat's line. A midline incision with medial parapatellar approach was used. Knee compartments and ACL integrity were evaluated. Femoral tracking arrays and a medial condylar checkpoint were positioned for robotic guidance. Registration of the hip center and trochlear surface, along with cartilage mapping, facilitated optimal implant alignment and orientation. The robotic burr was then guided within a haptic boundary to prepare the trochlear surface. After the trochlear trial implant was placed, the patella was manually resurfaced. Trial implants were tested for patellar tracking, and both trochlea and patella components were cemented. All instruments were removed, and the wound was closed in standard fashion.
<i>Batailler et al.</i>	VAS for pain, KSS, Kujala score, satisfaction rate, Caton De-Schamps index, patellar tilt, frontal alignment of the trochlea, complications	PFOA	Revision PFA; associated surgical procedures (e.g. ACL reconstruction, medial or lateral UKA)	Journey® Patellofemoral Joint System with NAVIO© Robotic System (<i>n</i> =17) Restoris© MCK Patellofemoral System with MAKO Robotic Arm (<i>n</i> =42)	X-ray (NAVIO system) X-ray and CT scan (MAKO system)	The NAVIO© system enables intraoperative planning through real-time mapping of femoral condyles and trochlea using percutaneously placed tracking sensors. It generates a 3D model of the patient's cartilage and bone structure for determining implant size and positioning. A robotic burr, guided by infrared tracking and touchscreen controls, performs bone resection with continuous limb monitoring. Patellar resection is manual. The MAKO system uses a preoperative CT scan for surgical planning (implant size and the femoral positioning). After placing tracking arrays, the femur is aligned to the CT model through anatomical points. Bone resection is executed by a robotic arm following the preplanned path, while patellar resection is done conventionally. Femoral alignment can be adjusted intraoperatively based on patellar tracking during knee flexion.

Table 3 (continued)

Study	Outcomes	Inclusion criteria	Exclusion criteria	Implant design and Robotic system	Pre-operative imaging technique	Surgical Technique
<i>Katzman et al.</i>	LOS, ROM at 6 months, infections, reoperations, time to revision, revisions, non-conversion re-operations, conversion to TKA, manipulation	PFA	Acute trauma; inflammatory arthritis; chondroblastoma; acromegaly; Paget's disease	Journey® Patellofemoral Joint System with NAVIO® Robotic System ($n=32$) Restoris® MCK Patellofemoral System and MAKO Robotic Arm ($n=62$)	X-ray (NAVIO system) X-ray and CT scan (MAKO system)	NR
<i>Pacchiarotti et al.</i>	ROM, VAS for pain, Kujala score, OKS, complications, satisfaction rate	Primary causes of PFOA; severe isolated PFOA associated with anterior knee pain; symptoms persisting for over a year, intensified by activities stressing the PFJ, impeding work and daily tasks, and unresponsive to conservative treatment; ROM within -10° of extension and 110° of flexion	Inflammatory knee arthropathy; femoro-tibial instability; tibio-femoral OA; femoro-tibial lesions >6 mm in diameter; low patella; varus and valgus deformity $>5^\circ$; decreased ROM	Journey® Patellofemoral Joint System with NAVIO® Robotic System	X-ray	The surgery, performed under spinal anesthesia via a mid-vastus approach with lateral patellar eversion, allowed cartilage assessment and osteophyte removal. Femoral tracking arrays were placed intra-incisionally (one above the patella facing the femoral center and another positioned parallel through a guide). An infrared-guided probe was used to digitize landmarks and generate a 3D model of the patient's distal femur and trochlea. Precise bone morphing was guided by anatomical references including the Whiteside line and mechanical axis. Implant positioning was planned in three planes, ensuring proper sizing, alignment, and patellar tracking. The femur was shaped using a haptically controlled high-speed burr guided by a color scale on the monitor for precision, followed by conventional patellar preparation. Trial and final components were tested and cemented after confirming stability and tracking.

Table 3 (continued)

Study	Outcomes	Inclusion criteria	Exclusion criteria	Implant design and Robotic system	Pre-operative imaging technique	Surgical Technique
<i>Noyes et al.</i>	Cincinnati Knee Rating system sports activity and symptoms rating scale, patient psychometric ratings of the substantial clinical benefit, patient acceptable symptoms state, Cincinnati Knee rating system occupational rating, VAS for pain, 12-item short form health survey, complications	≤ 50 years; skeletal maturity; non-inflammatory PFOA with severe symptoms; functional impairment refractory to treatment; ROM minimum of 5°-125°	Medial or lateral tibio-femoral OA; varus or valgus malalignment (mechanical axis > 5°); associated knee joint instability; loss of knee motion; tibiofemoral rotational malalignment (anteversion 20° or tibial torsion > 30°); alcohol and drug abuse; disabling OA of other joints; major systemic or autoimmune diseases or active infection	Restoris© MCK Patel-lofemoral System with MAKO Robotic Arm	X-ray and CT scan	NR
<i>Ziedas et al.</i>	2-Year Revision, overall revision, conversion to TKA, 30-day complications, 90-day complications, 90-day emergency department visits, joint related 90-day readmission, non-joint related 90-day readmission, prosthetic joint infection, wound issue, DVT/PE, return to OR	≤ 60 years; isolated PFOA	NR	Restoris© MCK Patel-lofemoral System with MAKO Robotic Arm	X-ray and CT scan	NR
<i>Leie et al.</i>	CPR at -5 years, revision rate and causes of revision	Isolated PFOA	NR	Restoris© MCK Patel-lofemoral System with MAKO Robotic Arm Journey® Patello-femoral Joint System with NAVIO© Robotic System	X-ray and CT scan	NR

Table 3 (continued)

Study	Outcomes	Inclusion criteria	Exclusion criteria	Implant design and Robotic system	Pre-operative imaging technique	Surgical Technique
<i>OKS</i> , Oxford Knee Score; <i>UCLA</i> , University of California at Los Angeles; <i>VAS</i> , Visual Analogue Scale; <i>KSS</i> , Knee Society Score; <i>PFOA</i> , Patella-Femoral Osteoarthritis; <i>UKOA</i> , Unicompartimental Knee Osteoarthritis; <i>CT</i> , Computed Tomography; <i>ROM</i> , Range of Motion; <i>PFJ</i> , Patella-Femoral Joint; <i>ACL</i> , Anterior Cruciate Ligament; <i>UKA</i> , Unicompartimental Knee Arthroplasty; <i>LOS</i> , Length Of Stay; <i>TKA</i> , Total Knee Arthroplasty; <i>PFA</i> , Patello-Femoral Arthroplasty; <i>OA</i> , Osteoarthritis; <i>DVT</i> , deep vein thrombosis; <i>PE</i> , pulmonary embolism; <i>OR</i> , operating room						

		Risk of bias domains							
		D1	D2	D3	D4	D5	D6	D7	Overall
Study	Turktas et al.								
	Selvaratnam et al.								
	Batailler et al.								
	Katzman et al.								
	Pacchiarotti et al.								
	Noyes et al.								
	Ziedas et al.								
	Leie et al.								

Domains:

D1: Bias due to confounding.

D2: Bias due to selection of participants.

D3: Bias in classification of interventions.

D4: Bias due to deviations from intended interventions.

D5: Bias due to missing data.

D6: Bias in measurement of outcomes.

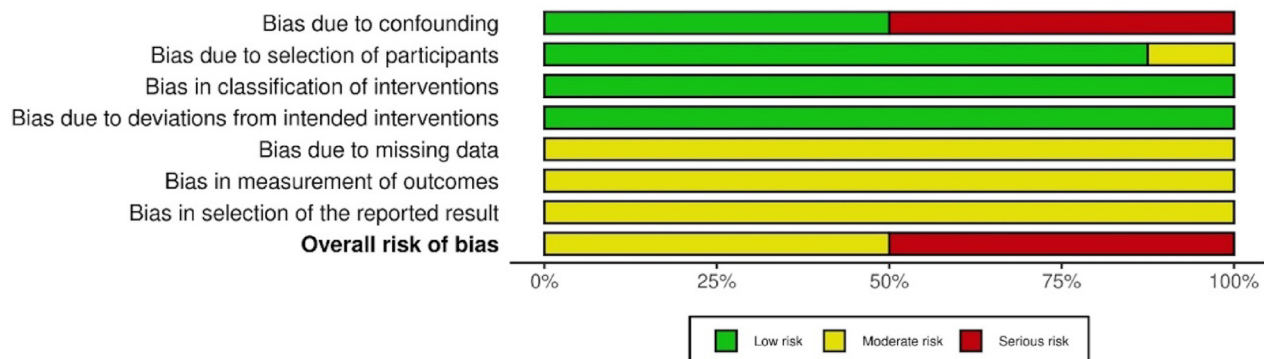
D7: Bias in selection of the reported result.

Judgement

⊗ Serious

⊖ Moderate

⊕ Low

**Fig. 2** Robins-I visual tool for risk of bias assessment of the included articles

Four studies [16, 26, 30, 31] involving 2449 patients (861 treated with RA-PFJA and 1588 with conventional PFJA) were comparative studies. The meta-analysis of primary outcomes (reoperation rate) and secondary outcomes (revision rate for all causes and revision for implant-related complications) was performed to compare the conventional PFJA and RA-PFJA.

The details of the study findings are reported within Tables 4, 5 and 6.

Functional outcomes

RA-PFJA demonstrated excellent knee function at the final follow-up assessment with weighted mean scores of 87.4 ± 14.1 points for the Kujala score [16, 27], 39.6 ± 5.4 points for the OKS [27–29], and 81.0 ± 14.2 points for the KSS [16, 28].

The pre-operative values were reported only for OKS [27–29]. The weighted means and weighted standard deviations for the pre-operative OKS score were 18.7 ± 5.8 points, with a mean difference of 20.9 ± 9.4 points ($p < 0.001$), indicating a statistically significant improvement in postoperative knee function.

These findings are further detailed in Table 4, which illustrates the pre- and post-operative functional score values across the study cohort.

Clinical outcomes

Pain levels, measured by the VAS score, were assessed in 4 studies [16, 25, 27, 28].

The pre-operative pain level was 7.4 ± 0.9 points, according to the VAS score, indicating a high level of subjective pain before surgery. RA-PFJA patients experienced substantially reduced pain: the weighted mean VAS score reduced to 1.8 ± 1.4 points, with an average improvement of $5.6 \pm$

1.2 points ($p < 0.001$). Furthermore, one study [27] reported that patients treated with RA-PFJA were less dependent on analgesic medications after the surgery compared to those who underwent conventional PFJA, suggesting better pain management with the robotic-assisted procedure.

Overall satisfaction rate was assessed by 3 studies [16, 27, 29]. Specifically, patient satisfaction after RA-PFJA was generally high, with a weighted mean of patients satisfied or very satisfied of $63.1 \pm 12.6\%$.

Details of clinical outcomes are reported in Table 5.

Complications, reoperations and revisions

The RA-PFJA was associated with a low overall complication rate (30% non-robotic vs. 15% robotic) across the studies included in the analysis. The most frequently reported complications were implant loosening (1% non-robotic vs. 0.2% robotic), patellar maltracking (0.4% non-robotic vs. 0.3% robotic), and progression of osteoarthritis to other compartments of the knee (7.2% non-robotic vs. 5.3% robotic). Despite the presence of these potential adverse events, the overall incidence remained low.

A detailed summary of the types and frequencies of complications reported in the included studies is presented in Table 6, providing further insight into the safety profile of RA-PFJA.

The re-operation rate for any cause was 9.6% in the non-robotic group vs. 6% in the robotic group. The main cause of reoperation was disease progression.

The RA-PFJA demonstrated a low revision rate, with a cumulative rate of only 3.3% at a mean follow-up of 3 years, suggesting enhanced mid-term durability of the implants.

Meta-analysis of comparative studies [16, 26, 30, 31] was performed, focusing on reoperation rate in conventional PFJA and RA-PFJA.

Funnel plot analysis revealed a low risk of publication bias with high homogeneity of included studies (Fig. 3).

Table 4 Functional outcomes

Study	Pre-operatively			Post-operatively		
	Kujala Score (mean $\pm$ SD)	OKS (mean $\pm$ SD)	KSS	Kujala Score (mean $\pm$ SD)	OKS (mean $\pm$ SD)	KSS (mean $\pm$ SD)
<i>Turktas et al.</i>	NR	21.7	56	NR	33.5	68.3
<i>Selvaratnam et al.</i>	NR	16	NR	NR	42	NR
<i>Batailler et al.</i> †						
Image Free	NR	NR	NR	82.8 ± 15.3	NR	88.2 ± 18.5
Image Based	NR	NR	NR	88.0 ± 15	NR	86.8 ± 10.8
<i>Katzman et al.</i> ‡	NR	NR	NR	NR	NR	NR
<i>Pacchiarotti et al.</i>	34.56 ± 23.3	17.3 ± 10.3	NR	90.2 ± 8.6	46.3 ± 1.8	NR
<i>Noyes et al.</i>	NR	NR	NR	NR	NR	NR

SD, Standard Deviation; OKS, Oxford Knee Score; KSS, Knee Society Score

† Results reported refer to the robotic group, detected at the last follow up

‡ Results reported refer the robotic group, detected at 6 months follow up

Table 6 Complications and revisions

Study	30-day compli- cation	90-day complication	Infection	DVT	Manipulation	Arthroscopic debridement	PFJ Revision	TKA revision	Implant loosening	Complex regional pain syndrome	Fracture
<i>Turktaş et al.</i>	NR	NR	0	1	1	1	0	2	0	NR	1 (Distal third of the femur)
<i>Selvaram et al.</i>	NR	NR	0	0	NR	NR	0	NR	0	NR	NR
<i>Batailler et al.*</i>	NR	NR	NR	NR	NR	NR	3	NR	NR	NR	NR
<i>Kazman et al.</i>	NR	NR	1	NR	30 †	30 †	2 †	17	2 †	NR	NR
<i>Pacchiarotti et al.</i>	NR	NR	NR	NR	NR	NR	NR	1	0	NR	NR
<i>Noves et al.</i>	NR	NR	1	NR	5	NR	NR	NR	NR	5	NR
<i>Ziedas et al.</i>	3	6	NR	0	NR	NR	3	3	NR	NR	NR
<i>Leite et al.</i>	NR	NR	NR	NR	NR	NR	9	30	NR	NR	NR

DVT, Deep Vein Thrombosis; PFJ, Patello-femoral Joint; TKA, Total Knee Arthroplasty

† Totally 30 knees required non-conversion procedures (manipulation or arthroscopic debridement). Only 2 knees underwent patellofemoral joint revision due to aseptic loosening of the implant or maltracking.

Patients who underwent RA-PFJA had a significantly lower reoperation rate compared with those undergoing conventional PFJA (6.3% vs. 8.6%; OR 0.67, 95% CI 0.48–0.94; $p=0.02$) (Fig. 4).

The revision rate for all causes of revision was assessed in all 4 comparative studies [16, 26, 30, 31] with high heterogeneity ($I^2 = 75\%$) among studies. The RA-PFJA group had a revision rate of 6.5% at final follow-up, compared to 7.8% in the conventional technique group ($p = 0.80$). The meta-analysis of all-cause revision rates is summarised in Fig. 5.

The specific causes of revision were detailed in 4 studies [16, 26, 30, 31]. A separate analysis of implant-related revisions was conducted, including aseptic loosening, implant breakage, wear, malalignment and patellar instability.

The meta-analysis of revision rate for implant-related causes revealed low heterogeneity ($I^2=22\%$) among studies. RA-PFJA group showed a significantly lower revision rate for implant-related causes compared with the conventional technique (0.7% vs. 1.9%; OR 0.32, 95% CI from 0.14 to 0.76; $p=0.01$) (Fig. 6).

Length of hospital stay (LOS)

Only two studies [26, 31] assessed LOS following PFJA. Patients undergoing RA-PFJA had a significantly shorter LOS compared with those treated with conventional PFJA, with weighted means of 1.3 ± 1.2 days and 1.6 ± 1.3 days, respectively ($p = 0.01$). The mean difference was -0.34 days (95% CI: -0.61 to -0.07). This suggests that robotic assistance can reduce hospitalisation by approximately one day for every three procedures performed.

Discussion

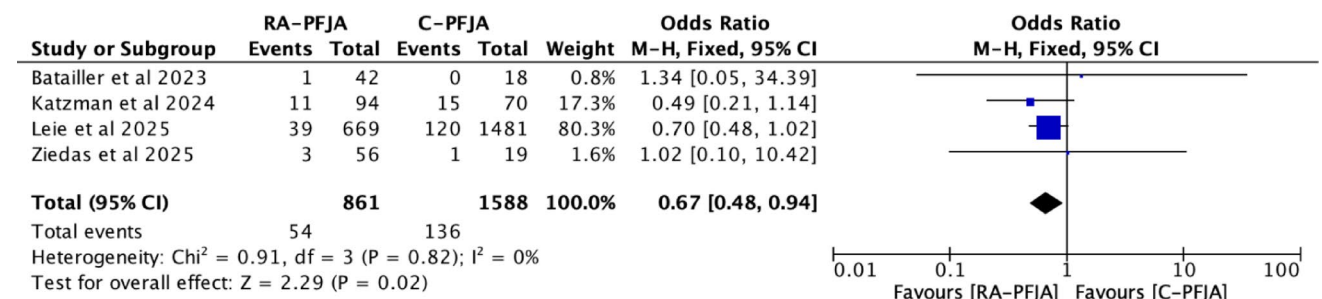
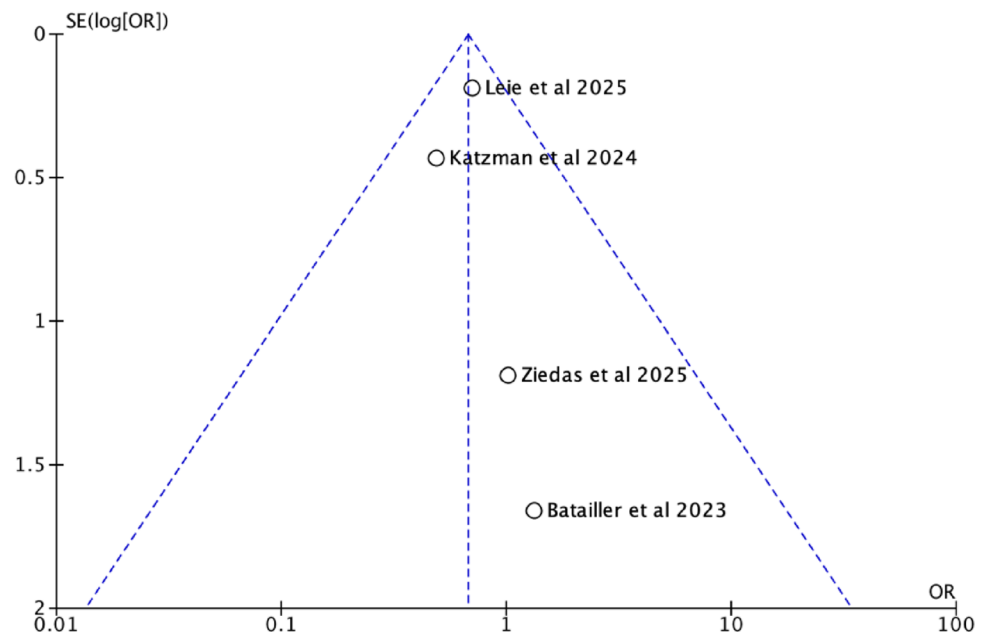
The findings of this systematic review underscore the growing and increasingly central role of robotic-assisted surgery in the field of PFJA.

The RA-PFJA showed several reproducible, patient-tailored technical benefits. One of the key advantages is the enhanced precision in implant positioning, which has been repeatedly identified as a crucial factor in determining both short- and long-term success of PFJA [6, 27, 29]. Malalignment, particularly in the axial plane, can result in complications such as patellar maltracking, instability, increased polyethylene wear, and early implant failure [32]. Robotic systems allow for real-time intraoperative assessment of bone morphology and dynamic kinematics, facilitating personalised surgical planning and execution [13]. This level of precision is difficult to achieve with conventional manual

Table 5 Clinical outcomes

Study	Pre-operatively		Post-operatively		
	VAS (value±SD)	ROM (°)	VAS (value±SD)	Satisfaction rate (%)	ROM (° ± SD)
<i>Turktas et al.</i>	8	115	2.1	NR	123
<i>Selvaratnam et al.</i>	NR	NR	NR	8	NR
<i>Batailler et al.</i> †					
Image Free	NR	NR	1.9±1.8	70.6	NR
Image Based	NR	NR	1.8±1.7	48.4	NR
<i>Katzman et al.</i> ‡	NR	NR	NR	NR	122.0
<i>Pacchiarotti et al.</i>	7.9±1.4	NR	1.10±1.4		
High Satisfaction				61	
Satisfaction				33	
Dissatisfaction				6	
Flexion Max					131.11±10.5 †
Extension Min					1.67±3.5 †
<i>Noyes et al.</i>	6.80	NR	1.87	NR	NR

VAS, Visual Analogue Scale; SD, Standard Deviation; ROM, Range of Motion
† Results reported refer to the robotic group, detected at the last follow up
‡ Results reported refer the robotic group, detected at 6 months follow up

Fig. 3 funnel plot assessing the risk of publication bias of included studies**Fig. 4** Forest plot of reoperation rate in conventional patello-femoral joint arthroplasty (C-PFJA) and robotic-assisted patello-femoral arthroplasty (RA-PFJA)

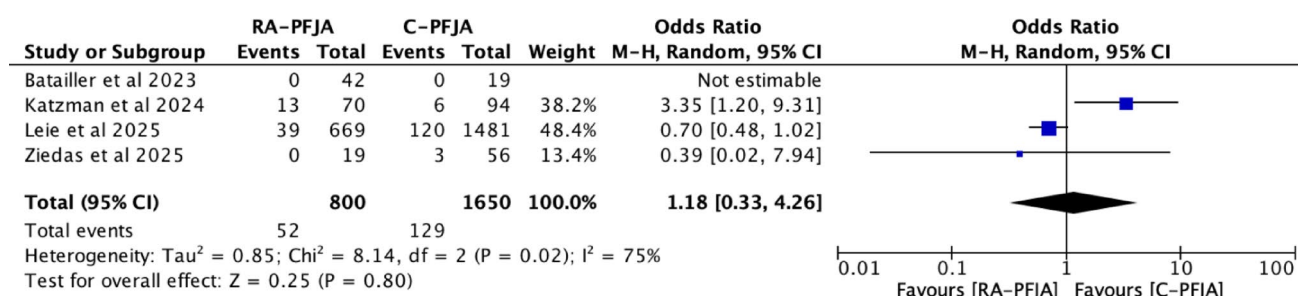


Fig. 5 Forest plot of revision rate for all causes in conventional patello-femoral joint arthroplasty (conventional-PFJA) and robotic-assisted patello-femoral arthroplasty (RA-PFJA)

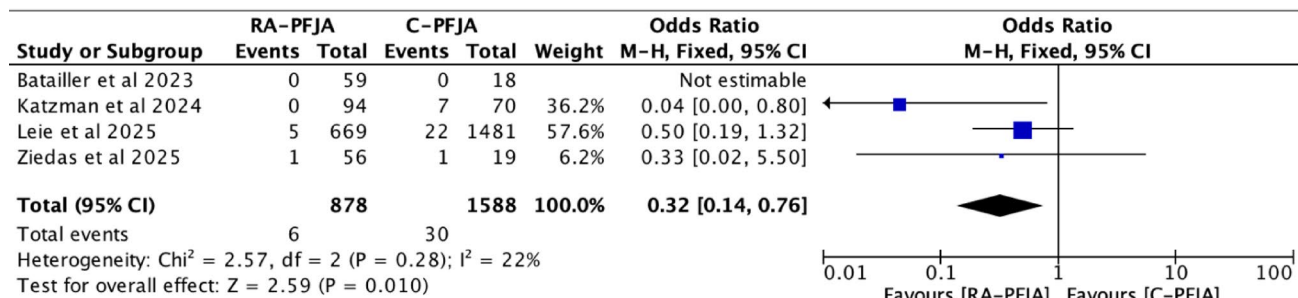


Fig. 6 Forest plot of revision rate for implant-related failures in conventional patello-femoral joint arthroplasty (conventional-PFJA) and robotic-assisted patello-femoral arthroplasty (RA-PFJA)

instrumentation, especially considering the variability in trochlear and patellar morphology among patients suffering from knee OA [5, 33]. Furthermore, by allowing for more accurate bone resections, improved rotational alignment, and balanced knee soft tissues, robotic platforms have demonstrated superiority in minimising malalignment and implant-related complications [14]. Finally, the ability to intraoperatively fine-tune component positioning reduces the risk of overstuffing or under-correction of the trochlear groove, which is a known source of anterior knee pain and dissatisfaction in PFJA [8, 13].

These technical advantages translate into measurable clinical benefits. Among these, one consistent finding was the effectiveness in restoring an active lifestyle, with up to 80% of younger patients returning to low-impact sports [16, 25–31]. Furthermore, robotic-assisted techniques contribute to significant improvements in the OKS, suggesting a meaningful enhancement in patients' ability to perform daily activities, participate in low-impact sports, and regain independence postoperatively [16]. In addition to functional gains, RA-PFJA has been associated with low postoperative pain levels. Indeed, the VAS scores were significantly reduced in robotic cohorts, highlighting the benefit of minimised soft tissue disruption and more precise implant fit [26]. These findings are particularly important in the context of fast-track rehabilitation protocols, where early mobility and pain control are key predictors of overall recovery and patient satisfaction [34].

Beyond clinical improvements, the technical advantages also have a positive impact on complication rates and implant survivorship. In fact, robotic assistance has been associated with reduced reoperation rate and implant-related complications [16, 25–31]. In this review, the overall complication rate for RA-PFJA was 15.8% at a mean follow-up of three years with a 7% revision rate and 6% reoperation rate. These data are lower than the rates traditionally reported for conventional PFJA. This finding is confirmed by Ziedas et al. [31], demonstrating that patients treated with conventional PFJA had a higher complication rate within 3 months ($OR\ 3.84$, $p = 0.04$). One study in particular [27] emphasised that maltracking and abnormal PF loading are major contributors to early implant failure, and their mitigation through accurate alignment may extend implant longevity. These findings are confirmed by the present meta-analysis, demonstrating a significantly reduced implant-related failure rate, enhancing the protective role of robotic surgery ($OR = 0.32$, $p = 0.01$).

Despite these benefits, the widespread adoption of RA-PFJA remains limited by several challenges. Foremost among these is the increased cost associated with robotic platforms. Since the high acquisition and maintenance costs of robotic systems may limit their feasibility for institutions with restricted budgets [35]. Moreover, the cost-effectiveness of RA-PFJA compared to conventional approaches is still under investigation [36]. While improved functional outcomes and reduced revision rates may offset the initial

costs over time, definitive economic evaluations are required to guide policy decisions and institutional investments.

Another important aspect is the learning curve, since robotic-assisted techniques remain partly reliant on the surgeon's expertise [37]. Transitioning from conventional manual instrumentation to a robotic workflow requires dedicated training, which may temporarily increase operative time and affect early clinical outcomes [16, 38]. Nonetheless, once the learning curve is overcome, studies have shown that robotic-assisted procedures can achieve consistent results with a high degree of reproducibility, even in anatomically complex or borderline cases [39].

Furthermore, long-term data on the survivorship and durability of RA-PFJA are currently limited. While short- and mid-term outcomes are encouraging, further prospective studies with extended follow-up are necessary to confirm whether the early benefits translate into sustained improvements over 10 or more years [26]. This is particularly important given the relatively younger age and higher functional demands of patients undergoing isolated PFJA compared to those receiving total knee arthroplasty [40].

This study presents several limitations that must be mentioned. First, the short follow-up period of the included studies, often associated with small sample sizes and serious or moderate risk of bias, limits the strength, and generalizability of the conclusions, particularly regarding the long-term outcomes. Additionally, there is a lack of randomised controlled trials specifically addressing this topic, which represents a major limitation in terms of the quality of available evidence. While some large registry-based studies were included, these data sources tend to lack detailed clinical information and may underestimate the incidence of specific variables and patients' reported outcomes. These factors collectively constrain the depth of clinical interpretation and the external validity of the results. Nevertheless, this review has relevant strengths. It represents the first systematic review and meta-analysis focused on RA-PFJA, a topic of growing relevance in modern joint replacement surgery. Moreover, despite the rarity of isolated PF and strict indications for PFJA, this work provides an important synthesis of current evidence, supporting future prospective research and improved clinical decision-making in this evolving area of orthopaedic practice.

Future investigations should confirm these promising results through large, prospective, randomized studies with longer follow-up and standardized outcome reporting. Integrating quantitative intraoperative data – such as dynamic tracking and soft-tissue tensioning – may help clarify how surgical precision translates into functional recovery. Finally, the evolution of robotic platforms toward AI-driven planning and sensor-assisted feedback is expected to further

enhance personalization, reproducibility, and long-term implant success in isolated patellofemoral arthroplasty.

Conclusion

The RA-PFJA represents a significant advancement in knee surgery, offering excellent functional results, and low revision rate at short to mid-term follow-up. While the current evidence supports its use, particularly in well-selected patients, further research is needed to establish long-term outcomes and the cost-effectiveness of the procedure. As robotic platforms become more accessible and integrated into clinical practice, ongoing innovation and high-quality comparative studies will be essential to define their definitive role in the orthopaedic surgical landscape.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Conflict of interests The authors declare no competing interests.

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