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Systematic Review

Robotic-assisted versus conventional total knee arthroplasty: a systematic review of functional outcomes and complications.

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Abstract

Background:

Robotic-assisted total knee arthroplasty (RA-TKA) improves the reproducibility of bone resection, component positioning, and limb alignment, but whether this technical precision produces clinically important functional or safety benefits over conventional total knee arthroplasty (C-TKA) remains uncertain.

Methods:

A structured systematic evidence update was conducted through 30 November 2025 using PubMed-indexed records, publisher pages, and reference-list checking. Systematic reviews and meta-analyses of randomized trials and eligible randomized comparative reports were prioritized. Two reviewers independently screened reports and extracted data. Published estimates were synthesized narratively without re-pooling overlapping trial populations.

Results:

Ten reports representing eight unique evidence sources were included. Randomized-trial meta-analyses consistently showed fewer alignment outliers and smaller mechanical-axis deviation with RA-TKA. A 2025 meta-analysis of 21 trials and 2,692 patients reported fewer alignment outliers (risk ratio 0.33, 95% confidence interval 0.19-0.59), a small Knee Society Score advantage (mean difference 1.03, 95% confidence interval 0.50-1.57), no meaningful range-of-motion benefit, and approximately 20 minutes longer operative time. Most pooled patient-reported outcomes and complication rates were similar. Selected platform-specific randomized evidence reported improved pain, satisfaction, and joint awareness, but generalizability was limited.

Conclusion:

RA-TKA provides a reproducible radiographic precision advantage; however, evidence for durable, clinically important functional superiority or fewer complications remains heterogeneous, short-term, and platform-dependent.

Need for future research:

Independent multicentre trials and registry-linked studies should use standardized patient-reported outcomes, predefined alignment strategies, transparent reporting of robotic-specific adverse events, economic evaluation, and follow-up of at least five to ten years.

Keywords: *robotic-assisted total knee arthroplasty; conventional total knee arthroplasty; patient-reported outcomes; complications; alignment; systematic review.*
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Introduction

Osteoarthritis is a major cause of pain and disability worldwide. The World Health Organization estimated that approximately 528 million people were living with osteoarthritis in 2019, with the knee representing the most frequently affected joint. The burden is expected to rise as populations age and the prevalence of obesity and previous joint injury increases.[1,2] For patients with end-stage symptomatic knee osteoarthritis who do not obtain adequate relief from non-operative treatment, total knee arthroplasty (TKA) remains an effective intervention for pain reduction and restoration of mobility.

Despite reliable implant survivorship and substantial average improvement after TKA, the operation does not produce an equally satisfactory result for every patient. Contemporary reviews suggest that dissatisfaction is lower than the historically quoted 20% in many modern cohorts, but persistent pain, stiffness, unmet expectations, and incomplete functional

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recovery remain clinically important.[3,4] These residual problems have stimulated interest in technologies designed to improve the reproducibility of component positioning and soft-tissue balance.

Conventional TKA relies on intramedullary and extramedullary guides, visual assessment, manual execution of bone cuts, and surgeon-directed balancing. Experienced surgeons can achieve excellent results with this approach, although small deviations from the planned resection or alignment target are unavoidable. Robotic systems combine preoperative or intraoperative anatomical modelling with navigation, constrained cutting or milling, and quantitative feedback on alignment and ligament balance. Platforms differ substantially: some are image-based and others imageless; some use a robotic arm, whereas others use a handheld sculpting tool or autonomous milling device. The intended alignment philosophy also varies from neutral mechanical alignment to restricted kinematic or functional alignment.

The central clinical question is not whether robotics can reduce radiographic outliers, because that advantage is relatively consistent, but whether improved precision translates into patient-perceived benefit, fewer complications, lower revision risk, or acceptable value for health systems. Robotic procedures can require longer setup and operating time, additional equipment and staff training, preoperative computed tomography for selected platforms, and fixation pins that introduce uncommon device-specific hazards. Learning-curve effects, platform evolution, surgeon preference, rehabilitation, and industry involvement further complicate interpretation.

Between 2023 and 2025, several randomized-trial systematic reviews, meta-analyses, and randomized comparative reports examined radiographic accuracy, patient-reported outcomes, complications, and operative efficiency.[5-11] Because these evidence sources overlap extensively, indiscriminate re-pooling can double-count participants and create false precision. The present review therefore provides a clinically oriented synthesis of evidence available through November 2025, distinguishes surrogate radiographic outcomes from patient-important outcomes, and identifies priorities for a defensible future update.

The objective of this review was to compare RA-TKA and C-TKA with respect to validated functional outcomes, pain, range of motion, perioperative recovery, complications, operative efficiency, and radiographic precision, while examining whether observed differences were clinically meaningful and consistent across robotic platforms.

Methodology

Review design and reporting framework

This manuscript was revised as a structured systematic evidence review and was reported in accordance with the applicable principles of PRISMA 2020 and contemporary Cochrane guidance.[12,13] It was not presented as a new study-level meta-analysis because complete primary-study extraction files and non-overlapping datasets were not available for independent re-pooling. Published pooled estimates were therefore retained as reported by their source reviews.

Registration and protocol

The review was not registered in PROSPERO or another systematic-review register. A separate prospective protocol was not prepared or publicly deposited. The absence of registration and an a priori protocol is acknowledged as a limitation, and future updates should be prospectively registered before screening begins.

Information sources and search strategy

A targeted search was completed through 30 November 2025 using PubMed-indexed records, open-access publisher pages, and the reference lists of recent systematic reviews. Search concepts combined terms for total knee arthroplasty, robotic or robot-assisted surgery, conventional or manual instrumentation, randomized trials, prospective comparative studies, functional outcomes, patient-reported outcome measures, complications, operative time, and alignment. The PubMed search framework was: ("Arthroplasty, Replacement, Knee"[Mesh] OR total knee arthroplast* OR total knee replacement*) AND (robot* OR robotic-assisted OR robot-assisted OR autonomous OR semi-active OR MAKO OR ROSA OR NAVIO OR CORI OR ROBODOC OR HURWA OR SkyWalker OR Yuanhua) AND (conventional OR manual OR jig-based OR standard instrumentation). Systematic reviews published from 1 January 2023 to 30 November 2025 were prioritized, while eligible randomized comparative reports available by the cutoff date were considered as direct supplementary evidence.

The original database export and complete screening log were not retained. Consequently, the study-selection pathway was reconstructed from the verifiable source set preserved in the manuscript and reference files. The reconstructed counts in Figure 1 should not be interpreted as the yield of a new exhaustive multi-database search.

Eligibility criteria

Inclusion criteria

- Adults undergoing primary TKA for osteoarthritis or another degenerative knee disorder.
- RA-TKA performed with an active, semi-active, robotic-arm, handheld, image-based, or imageless platform.
- A directly comparable C-TKA group using conventional manual or jig-based instrumentation.
- Systematic reviews or meta-analyses of randomized trials, randomized controlled trials, and prospective comparative studies considered as supplementary

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evidence when they addressed a distinct outcome not adequately represented in the randomized syntheses.
- Reporting of at least one validated functional outcome, pain measure, range of motion, satisfaction measure, perioperative outcome, complication, revision-related outcome, or radiographic alignment outcome.
- Full-text reports published in English and available by 30 November 2025.

Exclusion criteria

- Unicompartmental, patellofemoral, or revision knee arthroplasty.
- Cadaveric, biomechanical, technical, or simulation studies without patient outcomes.
- Single-arm case series, case reports, editorials, conference abstracts without adequate outcome data, and narrative reviews.
- Comparative studies that did not include a conventional manual TKA group.
- Duplicate publications from the same cohort when no unique outcome or follow-up information was provided. Companion reports with distinct outcomes were retained but were not counted as independent participant cohorts.
- Purely economic or resource-utilization reports without relevant clinical, functional, safety, or radiographic outcomes for the present review question.

Selection process

Two reviewers (SNC and TVV) screened each record and each full-text report independently against the eligibility criteria. Disagreements were resolved by discussion; when consensus was not reached, the senior reviewer (VH) acted as adjudicator. Reports from the same trial programme were linked using author names, sample size, recruitment setting, intervention platform, and follow-up period. No automation tool was used for eligibility decisions. Because the original database export was unavailable, the revised manuscript reports a reconstructed selection process limited to the retained and verifiable source set.

Data collection process

SNC and TVV independently collected data from each eligible report using a standardized extraction framework. Extracted information included publication year, study design, number of trials or participants, robotic platform, comparator, follow-up, outcome definitions, effect estimates, confidence intervals, complications, funding, and author-reported limitations. Extracted entries were compared, and discrepancies were resolved by consensus with adjudication by VH when required. Study investigators were not contacted because no missing value was essential to the narrative synthesis; where an estimate or methodological detail was unavailable, it was recorded as not reported rather than inferred.

Data items and outcome hierarchy

Primary outcomes were validated knee-specific functional or patient-reported measures, including the Oxford Knee Score (OKS), Knee Society Score (KSS), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Knee injury and Osteoarthritis Outcome Score (KOOS), Forgotten Joint Score (FJS), and Hospital for Special Surgery (HSS) score. Secondary outcomes were pain, range of motion (ROM), satisfaction, health-related quality of life, operative duration, blood loss, transfusion, length of stay, hospital utilization, overall and specific complications, manipulation under anaesthesia, revision, and robotic-specific adverse events. Alignment and component-positioning outcomes were treated as mechanistic or surrogate endpoints rather than direct evidence of patient benefit.

Study risk-of-bias assessment

Two reviewers (SNC and TVV) independently evaluated methodological limitations. Systematic reviews were appraised using AMSTAR 2 domains, with attention to protocol registration, search completeness, duplicate screening and extraction, justification of excluded studies, risk-of-bias methods, and investigation of heterogeneity and publication bias.[14] Directly included randomized trials were considered using the Cochrane RoB 2 domains: randomization process, deviations from intended interventions, missing outcome data, outcome measurement, and selective reporting.[15] Disagreements were resolved by consensus or adjudication by VH. Risk-of-bias findings informed interpretation and certainty but were not used as the sole basis for excluding an otherwise eligible study.

Reporting bias assessment

Risk of bias due to missing results was examined by comparing outcomes reported in trial publications with registrations or protocols when these were available and by extracting publication-bias judgements from the included meta-analyses. Funnel plots and statistical tests such as Egger regression were not performed because this review did not conduct a new meta-analysis and no outcome contained at least ten independent, non-overlapping studies within the reconstructed source set. The possibility of selective non-publication and outcome reporting was therefore addressed narratively.

Overlap management and certainty assessment

Certainty judgements were informed by the GRADE domains of risk of bias, inconsistency, indirectness, imprecision, and publication bias, but formal summary-of-findings tables were

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not generated because complete non-overlapping study-level data were unavailable.[16] Recent reviews included many of the same randomized trials, and some primary cohorts generated multiple publications for different outcomes or follow-up points. Pooled estimates from separate reviews were not combined. The contemporary reviews were treated as the principal syntheses, while companion reports from the same randomized programme were summarized as linked publications rather than independent cohorts.[5-11,17,18]

Data synthesis

Effect estimates are reported as published by the source review or primary study. Mean differences (MDs), risk ratios (RRs), and 95% confidence intervals (CIs) are presented where available. Direction of effect was harmonized so that higher functional scores generally favoured RA-TKA, whereas lower complication or alignment-deviation estimates favoured RA-TKA. Owing to overlapping datasets, heterogeneous follow-up, and platform variation, no new aggregate effect was calculated. The synthesis focused on consistency of direction, magnitude, clinical importance, and uncertainty.

Results

Study selection

The reconstructed retained source set contained 12 apparently relevant reports. All 12 reports were screened and assessed in full text. Two were excluded from the principal synthesis: a robotic-assisted unicompartmental knee arthroplasty study because the procedure did not meet the TKA eligibility criterion,[19] and a non-randomized prospective cohort because randomized evidence and randomized-trial syntheses were prioritized for the principal comparison.[20] Ten reports were included in the qualitative synthesis. These represented eight unique evidence sources: six systematic reviews or meta-analyses and two randomized trial cohorts. Three linked Bollars publications reported distinct clinical, radiographic, and alignment-classification outcomes from one randomized programme and were not counted as three independent cohorts.[9,17,18] The reconstructed selection pathway is shown in Figure 1.

Figure 1: Study-selection pathway for the retained source set

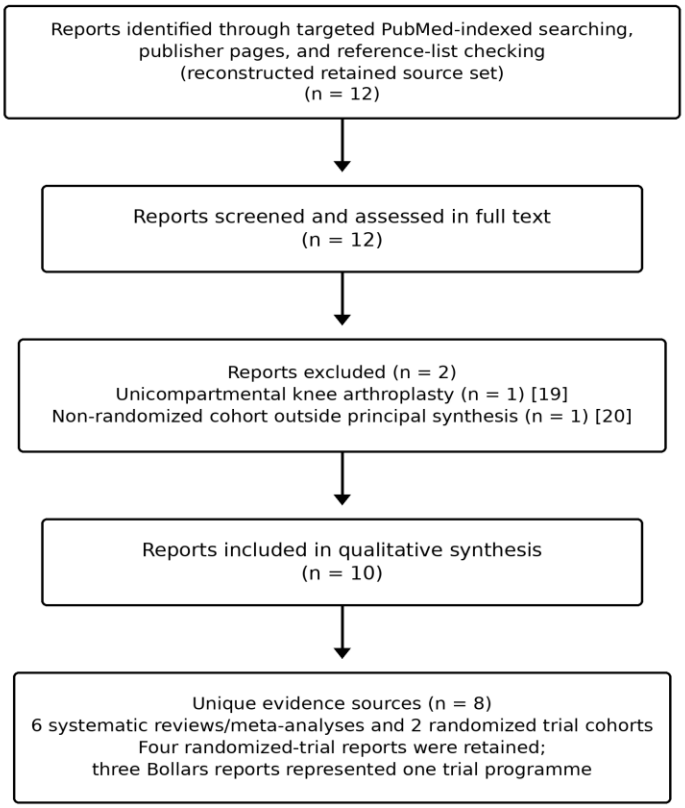

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Table 1: Characteristics of the major included evidence sources

Evidence source	Scope	Main outcomes	Overall interpretation
Mert et al., 2025[5]	25 randomized-trial reports; multiple platforms	Function, pain, precision, adverse events	Alignment improved; functional benefits inconsistent; operative time longer; risk-of-bias concerns
Ruangsomboon et al., 2023[6]	12 RCTs; 2,200 patients	Clinical and radiographic outcomes	Better radiographic accuracy; little or no functional difference; complications uncertain
Alrajeb et al., 2024[7]	7 RCTs; 1,942 knees	Alignment, PROMs, complications	Alignment favoured robotics; functional and complication outcomes broadly similar
Mostafa et al., 2025[8]	21 RCTs; 2,692 patients	Alignment, KSS, ROM, operative time	Fewer alignment outliers; small KSS gain; no ROM advantage; longer surgery
Bollars et al., 2025[9]	Multicentre RCT; 180 patients	12-month PROMs, pain, satisfaction, adverse events	Selected PROMs favoured one imageless handheld platform; independent replication required
Fu et al., 2024[10]	Updated systematic review and meta-analysis	Clinical and radiographic outcomes	Improved accuracy; clinical advantages heterogeneous
Daoub et al., 2024[11]	RCT systematic review and meta-analysis	Functional, radiographic, and safety outcomes	Precision favoured robotics; patient-important benefits inconsistent
Clement et al., 2024[22]	Randomized comparative trial	Knee-specific pain, function, expectations	Greater improvement in knee-specific pain, without consistent functional superiority

Note. RCT = randomized controlled trial; PROM = patient-reported outcome measure; KSS = Knee Society Score; ROM = range of motion.

Table 2: Reports that appeared potentially eligible but were excluded from the principal synthesis

Report	Why it appeared relevant	Reason for exclusion
Kayani et al., 2019[19]	Compared robotic-arm-assisted with conventional unicompartmental knee arthroplasty.	Excluded because unicompartmental knee arthroplasty was outside the prespecified primary TKA population.
Kayani et al., 2018[20]	Prospective cohort comparing robotic-arm assisted and conventional TKA.	Excluded from the principal randomized synthesis because allocation was non-randomized; findings were considered contextual only.

Note. TKA = total knee arthroplasty.

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Functional outcomes and patient-reported measures

Across systematic reviews, changes in functional scores were smaller and less consistent than radiographic gains. Most randomized-trial meta-analyses reported no significant difference or only small mean differences in validated PROMs.[5-8,10,11] The direction and magnitude of effects varied with outcome scale, follow-up time, robotic platform, alignment strategy, and the composition of pooled trials.

Mostafa and colleagues reported a small KSS advantage (MD 1.03, 95% CI 0.50-1.57) but no meaningful ROM difference (MD -0.34 degrees, 95% CI -6.19 to 5.51).[8] Ruangsomboon and colleagues reported little or no difference in WOMAC (MD -0.35, 95% CI -0.78 to 0.07) or ROM (MD -0.73 degrees, 95% CI -7.5 to 6.0).[6] These effects are below or uncertain relative to commonly used thresholds for clinically important change and should not be interpreted as universal functional superiority.[21]

Platform heterogeneity remained a major source of uncertainty. Reviews combined active, semi-active, robotic-arm, and handheld systems with different imaging requirements, autonomy, alignment philosophies, and learning curves.[5,10,11] Available subgroup evidence was insufficient to establish that a specific platform consistently produced superior patient-reported outcomes.

Randomized evidence

A multicentre randomized trial of 180 patients evaluated an imageless handheld system and reported better 12-month outcomes with RA-TKA: OKS 42.4 ± 5.4 versus 38.7 ± 7.2, KSS function 81.2 ± 12.3 versus 72.7 ± 15.1, KSS satisfaction 34.9 ± 5.2 versus 31.2 ± 7.9, EQ-5D index 0.883 ± 0.141 versus 0.833 ± 0.144, and FJS-12 73.2 ± 23.3 versus 53.6 ± 29.0.[9] Daytime and night-time pain scores were lower, ligament release was less frequent, and serious adverse events did not differ. Manufacturer funding and disclosed consultancy relationships increase the need for independent replication.

Companion reports from the same randomized programme showed improved implant-placement accuracy and examined postoperative changes in coronal plane alignment of the knee classification.[17,18] These publications provided distinct outcomes but were treated as one participant cohort. A separate randomized comparative trial found greater improvement in knee-specific pain after robotic-arm-assisted TKA without consistent superiority in overall function or quality of life.[22]

Pain, satisfaction, and early recovery

Pain benefits appeared most evident during early recovery or in selected platform-specific trials. The Bollars programme reported lower daytime and night-time pain and higher satisfaction at 12 months,[9] while Clement and colleagues reported a clinically meaningful improvement in knee-specific pain but not a broad functional advantage.[22] In contrast, pooled long-term PROMs frequently converged, suggesting that robotics can modify the recovery trajectory for selected patients without guaranteeing a superior outcome.

Complications and revision-related outcomes

Randomized-trial meta-analyses generally found no clear difference in overall complications between RA-TKA and C-TKA.[5-8,10,11] Confidence intervals were often wide, event definitions varied, and trials were primarily designed to assess alignment or function rather than uncommon harms. Therefore, the absence of a significant difference does not establish equivalence for infection, venous thromboembolism, fracture, manipulation under anaesthesia, or revision.

Evidence for revision reduction and long-term mechanical survival remained insufficient at the November 2025 cutoff. Most randomized trials had limited follow-up and inadequate statistical power for aseptic loosening, instability, periprosthetic fracture, or revision. Robotic-specific adverse events, including pin-site fracture or infection, tracker-related injury, conversion to manual instrumentation, registration failure, and technical interruption, were uncommon and inconsistently reported.

Radiographic precision and alignment

Radiographic accuracy was the most reproducible advantage of RA-TKA. The 2025 randomized-trial meta-analysis reported fewer alignment outliers (RR 0.33, 95% CI 0.19-0.59) and a smaller deviation from the planned mechanical axis (MD -0.93 degrees, 95% CI -1.20 to -0.66).[8] Other reviews similarly reported more accurate coronal alignment and component positioning, although the magnitude varied across platforms and measurement methods.[5-7,10,11]

The linked randomized radiographic report also demonstrated improved implant-placement accuracy with an imageless handheld system.[17] Precision should not be equated automatically with better function. A narrower distribution around an alignment target is clinically valuable only when the target is appropriate for the individual patient, and the gain affects symptoms, stability, wear, or survivorship.

Operative duration, blood loss, and resource use

Longer operative duration was the most consistent disadvantage. Mostafa and colleagues reported a mean increase of 19.94 minutes (95% CI 9.20-30.68) with RA-TKA.[8] Other randomized-trial reviews also described longer procedures, although the magnitude depended on platform, surgeon experience, operating-room workflow, and the stage of the learning curve.[5-7,10,11]

Blood-loss findings were heterogeneous and did not support a universal advantage for either technique. Cost-effectiveness depends on capital expenditure, disposable instruments, imaging, theatre throughput, case volume, length of stay,

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rehabilitation, and the uncertain value of avoiding future revisions. These variables are health-system specific and cannot be inferred from alignment accuracy alone

Table 3: Summary of quantitative findings

Outcome	Published estimate	Evidence source	Interpretation
WOMAC	MD -0.35 (95% CI -0.78 to 0.07)	12-RCT review[6]	No statistically significant or clinically meaningful difference
Range of motion	MD -0.34 degrees (95% CI -6.19 to 5.51)	21-RCT review[8]	No pooled ROM advantage
Alignment outliers	RR 0.33 (95% CI 0.19-0.59)	21-RCT review[8]	Consistent precision benefit
Mechanical-axis deviation	MD -0.93 degrees (95% CI -1.20 to -0.66)	21-RCT review[8]	Consistent radiographic benefit
KSS	MD +1.03 (95% CI 0.50-1.57)	21-RCT review[8]	Small effect; unlikely to be clinically important in isolation
Operative time	MD +19.94 minutes (95% CI 9.20-30.68)	21-RCT review[8]	Consistent disadvantage; platform- and experience-dependent
12-month OKS	42.4 ± 5.4 vs 38.7 ± 7.2	180-patient RCT[9]	Favoured one imageless handheld platform; generalizability uncertain
Serious adverse events	No significant between-group difference	180-patient RCT[9]	Single trial; insufficient for uncommon-harm conclusions

Note. CI = confidence interval; KSS = Knee Society Score; MD = mean difference; OKS = Oxford Knee Score; RCT = randomized controlled trial; ROM = range of motion; RR = risk ratio; WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index.

Risk of bias and certainty of evidence

Methodological quality varied across the included evidence. Common review-level limitations were absence of prospective protocol registration, incomplete lists of excluded full-text studies, overlap among primary trials, inconsistent handling of heterogeneity, and limited assessment of publication bias. Trial-level concerns included unavoidable lack of surgeon blinding, variable reporting of allocation concealment and assessor blinding, incomplete outcome data, selective reporting, platform heterogeneity, short follow-up, and industry involvement.[5-11] These limitations reduced confidence in claims of clinical superiority, particularly for uncommon complications and revision.

Table 4: Risk-of-bias considerations and pragmatic certainty ratings for major outcomes

Outcome domain	Pragmatic certainty	Reason for judgement
Alignment accuracy and outliers	Moderate	Consistent direction across randomized evidence and objective measurement, but targets and imaging methods varied.
Short-term pain and early recovery	Low	Selected trials showed benefit; findings were platform-specific and heterogeneous across time points.
Validated longer-term PROMs	Low	Small or inconsistent pooled differences, overlapping datasets, and limited independent long-term evidence.

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Outcome domain	Pragmatic certainty	Reason for judgement
Overall complications	Low	Trials were underpowered for uncommon events and used heterogeneous definitions.
Revision and loosening	Very low	Minimal comparative evidence with adequate duration and statistical power.
Operative time	Moderate	Consistently longer on average, but learning curve and workflow materially affected magnitude.

Note. Certainty ratings are pragmatic review-level judgements informed by GRADE domains rather than formal de novo evidence profiles.

Discussion

Principal findings and interpretation in relation to other evidence

This review supports three principal conclusions. First, robotic assistance consistently improves the accuracy with which a planned alignment or component position is achieved.[5-8,10,11,17] Second, average improvements in established functional scores are generally small or inconsistent, although selected randomized studies have reported clinically attractive gains in pain, joint awareness, satisfaction, or specific PROMs.[9,22] Third, complication rates appear broadly similar, but the evidence is not sufficiently large or mature to demonstrate equivalence or a reduction in revision risk.[5-11]

These findings are concordant with contemporary randomized-trial meta-analyses, which consistently separate a robust radiographic effect from a less certain patient-perceived benefit.[5-8,10,11] The small pooled KSS difference reported by Mostafa and colleagues illustrates the distinction between statistical and clinical significance,[8] whereas the larger platform-specific differences in FJS, OKS, pain, and satisfaction observed in the Bollars trial suggest that benefit can emerge under particular combinations of platform, alignment planning, workflow, and patient selection.[9] The Clement trial provides a similar caution: knee-specific pain improved, but broad functional superiority was not demonstrated.[22]

Why precision does not consistently translate into better PROMs

TKA outcome is multifactorial. Pain sensitization, expectations, psychological health, muscle strength, preoperative function, implant design, patellofemoral mechanics, analgesia, rehabilitation, and postoperative complications can influence recovery as much as a one- or two-degree difference in alignment.[3,4] Conventional TKA also produces substantial improvement in many patients, creating a ceiling effect for PROMs. Robotic systems can execute a plan precisely, but the technology cannot ensure that the selected target is optimal unless planning incorporates individual anatomy and soft-tissue behaviour.

Older robotic trials often evaluated mechanical alignment and first-generation active systems, whereas contemporary platforms increasingly support restricted kinematic or functional strategies. Pooling these generations assumes a common intervention that may not exist. Future reviews should stratify results by platform, imaging requirement, degree of autonomy, alignment philosophy, surgeon experience, implant constraint, and rehabilitation pathway rather than treating all robotic systems as interchangeable.

Complications and long-term mechanical outcomes

The absence of a statistically significant complication difference should not be interpreted as proof of equivalence. Composite endpoints can combine events of different clinical importance, while deep infection, venous thromboembolism, periprosthetic fracture, and revision require substantially larger samples than most trials provide.[5-11] Device-specific events, including pin-site fracture or infection, tracker injury, registration failure, and conversion to manual instrumentation, also require standardized outcome-specific reporting.

Improved alignment could theoretically reduce wear, instability, or loosening, but this pathway was not confirmed by adequately powered randomized trials or mature registry follow-up by November 2025. Durable evidence will require national registry linkage with robotic platform identifiers, alignment strategy, surgeon volume, competing-risk analysis, and at least five to ten years of follow-up.

Learning curve, cost, and implementation

Implementation decisions should extend beyond clinical scores. Capital and maintenance costs, disposable instruments, preoperative imaging, additional personnel, theatre scheduling, sterilization, and technical support can offset gains from lower inventory, shorter admission, or fewer revisions. High-volume centres can distribute fixed costs across more procedures and may reduce the operative-time penalty after workflow

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maturation, whereas low-volume centres may not achieve similar efficiency.

Training should address registration accuracy, tracker placement, plan modification, gap assessment, conversion to manual instrumentation, and recognition of device failure. Institutions adopting robotics should audit operative time, alignment outliers, conversions, complications, and PROMs. Procurement should be linked to measurable quality targets, independent outcome monitoring, transparent conflict-of-interest management, and a locally relevant economic model.

Conclusion

Robotic-assisted TKA consistently improves alignment and component-positioning precision compared with conventional manual TKA. Evidence available through November 2025 indicates possible platform-specific advantages in pain, satisfaction, and selected patient-reported outcomes, but these benefits are not uniform across studies or robotic systems. Average differences in established functional scores are generally small, operative time is longer, and robust evidence for lower complication or revision rates remains insufficient. Robotic assistance should therefore be presented as a precision technology with context-dependent clinical benefits rather than a universally superior operation. Independent long-term randomized and registry-linked studies are required to determine which patients and health systems obtain clinically meaningful value.

Clinical and research implications

Patients can be counselled that robotic assistance improves surgical precision and can improve selected aspects of recovery, but it does not guarantee a pain-free or perfectly functioning knee. Surgeons should regard robotics as a planning and execution aid rather than a substitute for exposure, balancing, judgement, and complication management. Potentially high-yield groups include patients with severe coronal deformity, unusual anatomy, previous extra-articular deformity, obesity, or cases in which individualized alignment and quantitative gap balancing are difficult with manual tools; however, definitive subgroup indications have not been established.

Future research should prioritize large, independently funded multicentre randomized trials with concealed allocation, blinded outcome assessment, standardized PROM time points, and prespecified minimal clinically important differences. Studies should report robotic platform, autonomy, imaging, alignment philosophy, implant, surgeon experience, conversions, and device-specific harms. Registry-linked follow-up should evaluate revision, loosening, instability, and periprosthetic fracture over five to ten years, while prospective economic analyses should incorporate local case volume, theatre throughput, rehabilitation, and quality-adjusted life-years.

Strengths and limitations

This review integrates contemporary randomized-trial meta-analyses and major randomized evidence available through 30 November 2025. It separates radiographic surrogates from patient-important outcomes, explicitly manages overlap among reviews and companion publications, describes risk-of-bias and reporting-bias procedures, and interprets statistical effects in relation to clinical importance.

The principal limitation is that the original database export, complete screening log, and a prospectively registered protocol were unavailable. Study selection was therefore reconstructed from the retained source set, and the review did not perform a new study-level meta-analysis. Included reviews differed in eligibility criteria, follow-up windows, risk-of-bias tools, and handling of duplicate cohorts. Some estimates were available only at review level, preventing independent verification. Formal funnel-plot or regression-based publication-bias analyses were not appropriate. These limitations reduce certainty and should be considered when interpreting the conclusions.

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List of abbreviations

AMSTAR 2, A Measurement Tool to Assess Systematic Reviews 2; C-TKA, conventional total knee arthroplasty; CI, confidence interval; CPAK, coronal plane alignment of the knee; EQ-5D, EuroQol 5-Dimension; FJS, Forgotten Joint Score; GRADE, Grading of Recommendations Assessment, Development and Evaluation; HSS, Hospital for Special Surgery; KOOS, Knee injury and Osteoarthritis Outcome Score; KSS, Knee Society Score; MD, mean difference; OKS, Oxford Knee Score; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; PROM, patient-reported outcome measure; RA-TKA, robotic-assisted total knee arthroplasty; RCT, randomized controlled trial; RoB 2, Risk of Bias 2; ROM, range of motion; RR, risk ratio; TKA, total knee arthroplasty; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

Registration and protocol

This review was not registered. A separate prospective review protocol was not prepared or made publicly accessible.

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No specific financial or non-financial support was received for this review. No funder or sponsor had any role in the review

question, literature selection, data interpretation, manuscript preparation, or decision to submit the work.

Competing interests

The authors declare that they have no competing financial or non-financial interests related to this review.

Availability of data, code, and other materials

The template data-collection form and the source-extraction matrix are not publicly deposited; they can be requested from the corresponding author. Data used in the narrative synthesis are presented in the manuscript tables and in the cited source reports. No new study-level meta-analytic dataset or analytic code was generated because overlapping published estimates were not re-pooled. The reconstructed study-selection figure and all other review materials used for interpretation are included in this manuscript.

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Author contributions

Conceptualization: SNC and VH. Methodology: SNC, TVV, and VH. Literature screening and data collection: SNC and TVV. Validation and adjudication: VH. Interpretation of evidence: all authors. Writing-original draft: SNC. Writing-review and editing: TVV and VH. Supervision: VH. All authors reviewed and approved the final manuscript and accept responsibility for the integrity of the work.

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