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# ROSA Robotic System vs. Manual Technique in Total Knee Arthroplasty: A Meta-analysis of Early Clinical, Radiological, and Safety Outcomes

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**Abstract**

**Background:** Deployment of the Robotic Orthopedic Surgical Assistant (ROSA) for use in total knee arthroplasty (TKA) is intended to improve implant positioning and lower limb axis alignment. Nevertheless, the question is whether this robotic technique produces better clinical and radiographic results than conventional TKA (CON-TKA). Given the lack of a definitive quantitative synthesis on this matter, we aimed to assess the radiographic accuracy, patient outcomes, and perioperative safety of ROSA-assisted TKA versus manual TKA.

**Methods:** We performed a systematic review and meta-analysis of comparative investigations identified through an exhaustive search of the Cochrane Library, Scopus, Embase, and PubMed, alongside leading Chinese repositories (CNKI and Wanfang). Literature published through March 2025 was compiled for analysis. Statistical computations were executed via STATA MP software (version 18.0).

**Result:** In total, 18 investigations satisfied the inclusion criteria. In terms of radiographic results, the ROSA-assisted TKA group had a lower risk of Hip-Knee-Ankle (HKA) alignment outliers than conventional TKA (P =0.03). Differences in other alignment parameters, including MPTA, LDFA, and posterior tibial slope, remained nonsignificant (all p > 0.05). As for clinical outcomes, differences were not statistically significant between groups (Knee Society Score (KSS, P =0.89; KSS function (P =0.05); Oxford Knee Score (OKS, P =0.45; Forgotten Joint Score (FJS, P =0.34; and VAS pain (P =0.57). There was only a statistical improvement in postoperative range of motion (ROM) in the ROSA group (P = 0.01); the minimal mean difference did not reach clinical relevance. ROSA-assisted procedures required significantly longer surgical times (MD 17.51 min; P < 0.001). No other differences were found for length of stay (P = 0.59), complication rates (P = 0.72), revision rates (P = 0.72), or patient satisfaction (P = 0.24).

**Conclusion:** ROSA-assisted TKA demonstrates a safe procedure that provides better radiographic accuracy in coronal alignment than conventional TKA. However, this radiographic precision doesn't lead to clinically relevant improvements in functional scores, PROMs, or ROM at short- to medium-term follow-up, while it is accompanied by increased operative time. To further validate these findings, subsequent randomized controlled trials with sufficient statistical

power and extended follow-up are warranted to determine whether ROSA's precise alignment translates into improved long-term implant survivorship.

**Keywords:** Arthroplasty, replacement, knee; robotic surgical procedures;ROSA system

## Introduction

The clinical benefit associated with total knee arthroplasty (TKA) managing terminal-stage knee osteoarthritis is well-established, however achieving ubiquitous patient satisfaction remains an elusive goal [1]. Interestingly, research suggests that around a large minority of patients (15–20%) are not satisfied with their surgical outcome[2]. Factors affecting this dissatisfaction include malposition of components and ongoing joint laxity [3, 4]. Traditionally, neutral mechanical alignment and restorative joint kinematics have been the cornerstone of successful TKA, but most conventional TKA (CON-TKA) techniques use either intramedullary or extramedullary jigs, which are highly prone to inherent variability and human error [5].

To overcome the aforementioned limitations, robotic-assisted TKA (RA-TKA) systems were introduced to refine surgical precision and enhance the reproducibility of the procedure [6]. The Robotic Orthopaedic Surgical Assistant Knee System (ROSA), in particular, seems to have found impressive clinical uptake among the robotics platforms[7]. The ROSA Knee System acts like a collaborative robotic assistant, which is made distinct from CT-dependent semi-active Mako platform and manual burr-driven NAVIO/CORI systems. It utilizes X-Atlas technology to promptly generate patient-specific 3D models of bones directly from routine preoperative 2D radiographs or through intraoperative image-less registration. Rather than relying on a haptic-guided saw or performing the indirect bone cutting choreography with the robot itself, the ROSA system employs a robotic arm to place an appropriately jiggered cutting guide; normal bone resections can then proceed using an oscillating saw. This adjunctive workflow retains surgeons' tactile feedback. It provides continuous updates on intraoperative soft-tissue dynamics and gap stability, which can be used to dynamically modulate alignment, resulting in patient-specific component alignment without the added expense or radiation exposure of preoperative CT imaging[8].

The comparative clinical superiority of ROSA-assisted TKA has been a point of continuing debate within the orthopedic community. Prior meta-analyses have reported on robotic-assisted TKA as an aggregate, but have generally combined data across disparate platforms (e.g., MAKO, ROSA, and ROSA) that vary significantly in haptic feedback, workflow, and preoperative requirements [9–11].

Zaidi et al. recently published a meta-analysis [12] that provided early insights into the ROSA platform; however, our study offers several unique advantages and additions. To start with, a major methodological advancement of our study against the review by Zaidi et al. is the most thorough implementation of quantitative meta-analysis. While Zaidi et al. provided a valuable systematic overview, they primarily relied on descriptive aggregations for clinical outcomes. Second, Zaidi's search concluded in mid-2023 and focused on uncontrolled, single-arm case series and cadaveric studies. In contrast, our analysis is limited to clinical cohorts, including multiple high-quality trials published in 2024 and 2026, which represent the best level of contemporary clinical evidence. Third, we extended performance beyond standard functional evaluation to include more sensitive patient-reported outcomes, such as FJS and satisfaction, which were not comprehensively addressed in previous reviews. Fourth, we have added additional evidence on the perioperative reliability of the ROSA system through granular analysis of safety metrics, such as PJI and revision rate. Thus, as far as we can determine, this investigation represents the most current and clinically relevant quantitative meta-analysis of the ROSA-assisted TKA literature. Accordingly, this meta-analysis aimed to systematically assess ROSA-assisted TKA vs. CON-TKA, focusing on radiographic alignment accuracy, clinical functional scores, and perioperative complication profile. We hypothesized that ROSA-assisted TKA would offer better radiographic accuracy but at the cost of prolonged operation time.

## Methods



This meta-analysis was executed in compliance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework [12].The study protocol was pre-recorded in the International Prospective Register of Systematic Reviews (PROSPERO) and assigned the identifier CRD420261335007. The complete registration details are publicly available via the PROSPERO portal.

**Search strategy**

An exhaustive retrieval was executed across various digital indexes—specifically Embase, Scopus, Web of Science, and the Cochrane Library—supplemented by searches within PubMed and several Chinese literature databases such as CNKI and Wanfang. With a cut-off date of March 2026, this search sought to identify published comparative studies that assess ROSA-TKA compared to CON-TKA. Supplementary Data 1 provides detailed search protocols including the specific keyword combinations and Boolean operators utilized for each database. Initial study selection involved a dual-investigator screening of titles, abstracts, and complete manuscripts by two reviewers (T.J.L. and J.W.L.) to determine eligibility. Any discordance encountered during this hierarchical assessment was reconciled through deliberation and consensus with a senior investigator.

**Inclusion and exclusion criteria**

Eligibility was limited to comparative investigations—encompassing randomized controlled trials (RCTs) and observational cohorts including case-control, prospective/retrospective studies involving participants diagnosed with terminal-stage knee osteoarthritis that directly compared ROSA-TKA with CON-TKA.

Primary data captured encompassed various patient-reported outcomes (PROs), specifically the Visual Analog Scale(VAS), Knee Society Score (KSS), Oxford Knee Score (OKS), Forgotten Joint Score (FJS), Knee injury and Osteoarthritis Outcome Score(KOOS). Functional measures were additionally measured, including range of motion (ROM), surgical duration, and hospital length of stay (LOS).Used to compare the accuracy of radiographic alignment were outlier rates for hip-knee-ankle (HKA) angle, posterior tibial slope (PTS), lateral distal femoral angle (LDFA) and medial proximal tibial angle (MPTA). Safety data were systematically assessed, reporting rates of periprosthetic joint infection (PJI) and revision surgery in addition to total complication rates. Eligible studies needed to report enough quantitative information for the calculation of either mean differences (MD) or risk ratios (RR).

Secondary literature, guideline documents, narrative reviews, letters to editors and editorials were all excluded using strict exclusion criteria.

**Data extraction process**

Data extraction was performed independently by two investigators (T.J.L. and J.W.L.), with any discordance reconciled through consensus involving a third reviewer (C.J.S.). The extraction process was conducted according to several parameters:1) study features, the first author, year of publication, nation of origin, follow-up duration, and study architecture;2) characteristics of the subjects such as age, gender distribution, and body mass index (BMI) at baseline and final evaluation;3) primary and secondary clinical endpoints. In instances where essential parameters were absent from the published reports, the corresponding authors were contacted and requested to provide missing details.

**Data Transformation**

When primary studies reported outcomes solely as medians alongside ranges or interquartile ranges (IQRs), the corresponding mean and standard deviation (SD) values were estimated according to the validated statistical frameworks described by Luo et al. [13] and Wan et al[14]. These established conversion techniques are recognized for providing reliable approximations of the necessary metrics for quantitative synthesis [15–18].

**Risk of Bias Assessment**

Methodological quality for non-randomized investigations was appraised via the Newcastle-Ottawa Scale (NO)[19], underscoring 3 essential dimensions: selection of cohorts, intergroup comparability, and outcome assessment. For RCTs, the assessment followed the criteria described in the Cochrane Handbook for Systematic Reviews of Interventions. Two investigators, T.J.L. and J.W.L., performed this assessment independently with discrepancies resolved through discussion or accessing a senior investigator.

**Data Analyses**

To pool the data, we utilized a random-effects meta-analytic framework. Specifically, the restricted maximum likelihood (REML) approach was employed to account for anticipated inter-study variability stemming from clinical and methodological discrepancies [20].All statistical analyses were conducted with STATA MP software. Continuous outcomes are reported as mean and standard deviation (SD). Heterogeneity across investigations was appraised through the $I^2$ statistic and Cochran's Q test.

All pooled results were expressed as point estimates with their respective 95% confidence intervals (CIs). Odds ratios (ORs) were calculated for the binary variables, which included patient satisfaction and rates of complications, revisions, periprosthetic joint infection (PJI), and radiographic outliers (HKA; MPTA; LDFA; PTS). Since these events were rare, we viewed them as ORs approximating RR under a rare-event assumption[18]. Continuous variables (operative time, LOS, ROM, and patient-reported outcomes: VAS; KSS, OKS, FJS) were pooled using mean differences (MD) as the measure of treatment effect. Statistical significance was defined by a two-sided p-value $< 0.05$. Moreover, to evaluate the stability of the meta-analysis findings, leave-one-out sensitivity analyses were executed.

**Search results**

The initial literature search yielded 633 citations across the queried electronic repositories. After removing 301 duplicates using reference management software, 332 unique articles were available for further review (Fig. 1). Each repository was searched according to comprehensive search protocols outlined in Supplementary Data 1. Evaluation of titles and abstracts resulted in the exclusion of 312 articles,because they did not fulfill the predefined eligibility criteria related to population, intervention or study design. An overview of the basic study characteristics for the included investigations[22–39] is provided in Table 2.

**Sample Characteristics**

In Tables 1 and 2, we present a summary showing the essential study characteristics and clinical outcome data reported. All investigations analyzed in this quantitative synthesis emerged from 2022 through 2026.

**Results**

**Quality Assessment**

Across the 16 observational investigations, methodological quality was appraised as moderate-to-good, with NOS scores falling between 6 and 8 out of a maximum of 9 (Table 3). These studies commonly displayed limitations such as constrained follow-up intervals and susceptibility to detection bias, which are well-documented challenges of non-randomized designs.

The Cochrane risk-of-bias framework was utilized to assess the two RCTs, revealing an overall satisfactory quality rating as summarized in Table 4. However, the risk of performance bias — especially in terms of blinding participants and personnel — was categorically judged to be high. This challenge is owing to both the nature of surgical procedures and the difficulty in adequately masking treatment status from patients, as well as operating surgeons.

**Sensitivity Analysis**

To verify the stability and integrity of the summarized findings,  leave-one-out sensitivity analyses were executed across each investigated outcome measure. Sequential exclusion of individual studies did not have a meaningful influence on the direction, size, or statistical significance of pooled effect sizes for any outcome. Importantly, none of the outcomes were sensitive to the removal of a specific study with significant heterogeneity ($I^2$). These findings confirm that our meta-analysis is extremely robust and not overly affected by the influence of any single study or potential bias (see Supplementary Data 2).

**Radiological Outcomes**

HKA outlier rates were reported in seven studies. The meta-analyses demonstrated significantly less risk of HKA outliers for ROSA cohort compared to conventional TKA, with a relative risk (RR) of 0.51 (95% CI 0.28 to 0.95, $p = 0.03$; [Fig. 2.1). In comparison, the risk of MPTA outliers was found to be comparable between both groups in two studies (RR 0.97 (95% CI 0.09

to 11.02, p=0.98; Fig. 2.2). There were also no mean differences in LDFA outliers among the techniques, with an RR of 0.34 (95% CI 0.09 to 1.27, p = 0.11; Fig. 2.3). Finally, while PTS outlier rates trended towards the ROSA group, this observed trend remained nonsignificant (RR 0.15, 95% CI 0.02 to 1.19, p = 0.07; Fig. 2.4).

**Clinical and Functional Outcomes**

Six studies reported the KSS and KSS function scores. Clinical KSS scores were comparable between ROSA-TKA and conventional TKA cohorts (MD 0.42, 95% CI -5.44 to 6.28, p = 0.89; Fig. 3.1). Likewise, in terms of KSS function subscore, pooled data did not show significant difference across groups (MD 6.31, 95% CI 0.01 to 12.62, p = 0.05; Fig. 3.2). Analysis of the OKS (5 studies) demonstrated nonsignificant differences (MD 0.57, 95% CI -0.92 to 2.07, p = 0.45; Fig. 3.3). Comparatively, there were no differences in KOOS between the two groups across three trials (MD 2.13, 95% CI -0.24 to 4.51, p = 0.08), as shown in Figure 3.4. In addition, synthesis of the FJS from three investigations yielded equivalent outcomes between cohorts (MD 3.56, 95% CI -3.80 to 10.92, p = 0.34; Fig. 3.5). Postoperative pain was evaluated using VAS in the six studies. Meta-analysis of pain demonstrated no difference postoperatively in patients undergoing ROSA TKA compared with conventional surgery (MD -0.12, 95% CI -0.54 to 0.30, p = 0.57; Fig. 3.6)

**.Perioperative Outcomes and Safety**

Regarding hospital length of stay (LOS), five studies provided data for comparison. Meta-analysis demonstrated comparable LOS durations between the ROSA-assisted and conventional TKA cohorts(MD -0.17, 95% CI -0.77 to 0.44, p = 0.59; Fig. 4.1). On the other hand, according to a meta-analysis of 11 investigations, the ROSA cohort required a significantly protracted surgical duration compared with manual techniques (MD 17.51, 95% CI 11.07 to 23.94, p < 0.001; Fig. 4.2),representing a disparity of both statistical and clinical importance. Nine studies evaluated postoperative ROM. The pooled analysis demonstrated a statistically significant improvement in ROM with ROSA robotic-assisted TKA compared with the conventional cohort. These small differences indicate that while the statistical superiority exists, it is unlikely to correspond to an actual meaningful clinical advantage for the patients (MD 4.32, 95% CI 1.13 to 7.51, p = 0.01; Fig.

4.3). Additionally, meta-analysis of four investigations demonstrated equivalent patient satisfaction rates between the robotic and manual techniques (RR 1.03, 95% CI 0.98 to 1.08, p = 0.24; Fig. 4.7).

The cohorts had similar safety outcomes and short- to medium-term implant survivorship. The overall complication rate, assessed by meta-analysis of nine studies for comparison between the ROSA and conventional groups, showed no difference (RR 1.11, 95% CI 0.65 to 1.88, P = 0.72; Fig. 4 .4). Likewise, PJI incidences (six studies; RR 1.12, 95% CI 0.39 to 3.19, p = 0.84; Fig. 4.5) and all-cause revision (seven investigations; RR 0.79, 95% CI 0.21 to 2.94, p = 0.72; Fig. 4.6), remained comparable between techniques.

## Discussion

The main finding of this meta-analysis is that ROSA robotic assistance statistically increases radiographic accuracy, as evidenced by lower rates of HKA axis outliers compared with conventional manual TKA. Nevertheless, the postoperative range of motion (ROM) in absolute terms favored the ROSA cohort by a slight statistical margin. Still, this negligible difference failed to reach the threshold for clinical relevance. Moreover, there was a significantly prolonged operative time associated with the robotic approach without a clear benefit in clinical functional scores (including KSS function), PROMs, length of stay, or complications.

One goal of TKA is to align component placements with planned targets to promote implant longevity and achieve optimal biomechanics. Our pooled data showed that the ROSA group had a 49% reduced risk for HKA outliers (RR = 0.51). This is in line with earlier literature regarding other robotic systems, wherein the intraoperative real-time feedback and execution of a robotic arm minimize inherent inaccuracies of traditional intramedullary/extramedullary cutting guides. Notably, no differences were found for specific outliers (MPTA, LDFA, PTS) in the coronal and sagittal planes. This non-significant finding is most probably due to a type II error, considering the low number of studies reporting these outcome parameters in our analysis.

One debate in the current RA-TKA literature is whether radiographic superiority translates into real benefits for patients. In conclusion, short-to-medium-term clinical and functional outcomes were comparable between ROSA-assisted and manual TKA, as no significant disparities were observed across all appraised parameters within this meta-analysis. In particular, the combined data showed no superiority for the robotic group in regard to both of the outcome measures: An objective Knee Society Score (KSS) ($P = 0.89$) and a functional subscore ($P = 0.05$). This finding was consistent across various Patient-Reported Outcome Measures (PROMs), including the OKS, KOOS, and postoperative VAS pain scores.

Moreover, using the FJS, a metric very sensitive to a patient's final ability to "forget" the artificial joint with regard to activities of daily living, the ROSA system did not show superiority. The uniform lack of significant differences across these heterogeneous scoring systems indicates a possible ceiling effect in contemporary TKA. This suggests that functional outcome measurements may not be able to detect subtle biomechanical optimizations afforded by robotics. It is equally likely, however, that the higher radiographic accuracy (i.e., fewer HKA outliers) achieved by the ROSA system simply does not translate to objectively significant functional or symptomatic improvement in early follow-up. The real advantage of such alignment accuracy is only theoretically evident in the long term with less polyethylene wear and enhanced implant survivorship (> 10-15 years), which remains a critical area for future investigation.

Although we found equivalence in the functional scores, a statistically significant increase was detected in postoperative ROM (MD = 4.32°; $P = 0.01$), favoring ROSA. Nonetheless, this result needs to be viewed in the perspective of the Minimal Clinically Important Difference (MCID).Previous studies have reported the MCID of knee flexion to range from 3.8°–6.4°[40]. Our pooled estimate of 4.32° also falls within this accepted range, nearing the bottom limit of clinical detection. This means, in some patients, there could be a noticeable functional change but the difference seems to be slight and not consistent for better function on more complex activities like traversing stairs or moving from sitting down to standing. Therefore, the finite statistical increase of 4.32 degrees identified in our review may lack true clinical significance.

The ROSA group also suffered a longer operative time (MD 17.51 minutes, $P < 0.001$) in terms of perioperative efficiency. This increase stems from multiple factors, including the need to place pins, the intraoperative optical registration used with this platform, and a learning curve for a new robotic platform. Luckily, this extra operative time did not affect the patients' safety. Our meta-analysis confirmed similar complication rates, PJI, and short-term revision rates between cohorts. Moreover, the LOS was similar, suggesting that the ROSA system does not yet offer any particular advantages over traditional TKA for early post-operative discharge or rapid recovery (ERAS) protocols.

## Limitations

Several limitations must be acknowledged. (i) Inclusion of retrospective cohort studies means that there will be inevitable selection bias, but we still used random-effects models to lower excess heterogeneity. Second, in terms of follow-up time, the present meta-analysis was based on studies for which a short-to-medium term follow-up seemed to be common. In the long term, the true benefit of improved radiographic accuracy in ROSA-TKA can be achieved only when there is reduced wear and improved implant survivorship (>10-15 years), which current data cannot ascertain. Finally, a high level of heterogeneity was observed in continuous variables such as operative time and ROM, which may be attributed to variations in surgical experience and institutional rapid recovery protocols among the included studies.

## Conclusion

The results of the present study suggest that ROSA-assisted TKA is a safe procedure that provides better radiographic accuracy in coronal alignment than conventional TKA. However, this radiographic precision doesn't lead to clinically relevant improvements in functional scores, PROMs, or ROM at short- to medium-term follow-up, while it is accompanied by increased operative time. To further validate these findings, subsequent randomized controlled trials with sufficient statistical power and extended follow-up are warranted to determine whether ROSA's precise alignment translates into improved long-term implant survivorship.

## Declarations

### Ethics approval and consent to participate

Ethical approval was not required for this study as it is a secondary analysis of previously published literature.

### Competing interests

The authors declare that they have no competing interests.


### Funding

None.


### Data availability statement

Study data are available from the corresponding author upon reasonable request.

### Authorship contribution statement

Tianjian Li and Jiawang Lou were responsible for the study's methodological design, data management, and evidence synthesis. Tianjian Li prepared the initial draft of the manuscript. Chunbo Huang provided essential resources and oversaw project administration, while Xiaofei Zhang conducted formal statistical computations and managed the software analysis. Changjiao Sun was responsible for research conceptualization and the primary supervision of data interpretation. Additionally, Changjiao Sun provided critical editorial refinements to the draft, and every author endorsed the submitted version.

### Table Legend

Table 1. Overview of methodological features and patient-specific data for all included cohorts.

Table 2. Summary of clinical outcome data and baseline parameters reported across the compiled studies.

Table 3. NOS quality appraisal for non-randomized investigations.

Table 4. Cochrane-based risk of bias profile across six domains for included RCTs.

## Figure legend

Fig. 1. PRISMA flow chart depicting the study selection process

Fig. 2. Forest plots assessing differences in the accuracy of radiographic alignment, focusing on outlier rates for HKA, MPTA, LDFA and PTS.

Fig. 3. Forest plots comparing patient-reported outcomes (PROs) comprising the VAS, KSS clinical and functional sub-scores, OKS, KOOS and FJS.

Fig. 4. Forest plots evaluating perioperative outcomes and safety profiles, including operative time, LOS, ROM, PJI, revision, complications, and satisfaction levels

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