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Comparison of Clinical and Radiological Results in Robotic-Assisted and Traditional Total Knee Replacement: A Comprehensive Systematic Review

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ABSTRACT

Background: Robotic-assisted total knee arthroplasty (RATKA) enhances surgical precision and prosthesis alignment compared to conventional total knee arthroplasty (COTKA), potentially improving outcomes and patient satisfaction for knee osteoarthritis. **Methods:** The review adhered to PRISMA 2020 standards and analyzed full-text English literature from 2014 to 2024. Literature sources included PubMed, SagePub, SpringerLink, and Google Scholar. **Result:** A total of 500 articles were retrieved from online databases (PubMed, SagePub, SpringerLink and Google Scholar). After three rounds of screening, ten articles directly relevant to the systematic review were selected for full-text reading and analysis. **Conclusion**: RATKA demonstrates superior radiological alignment and precision compared to COTKA, while achieving comparable functional outcomes and complication rates. The integration of robotic technology in orthopedic surgery holds promise, yet ongoing research is crucial to optimize its clinical application and enhance patient outcomes globally.

Keyword: robot-assisted total knee arthoplasty, conventional total knee arthoplasty, clinical outcomes, radiological outcomes

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INTRODUCTION

Osteoarthritis (OA) of the knee is the leading cause of knee pain in the elderly, affecting approximately 23% of the global population. This debilitating condition significantly impairs patients' quality of life, often leading to severe disability. As OA progresses, conservative treatments such as physical therapy, medications, and lifestyle modifications may become insufficient, necessitating surgical intervention. When conservative treatments fail, conventional total knee arthroplasty (COTKA) is typically recommended to restore function and alleviate pain.[1]

COTKA has been the standard surgical procedure for end-stage knee OA, with generally favorable outcomes. However, several surgical challenges can adversely affect the success of COTKA. Poor soft-tissue tension balancing and malalignment of the prosthesis are notable complications that can compromise the effectiveness of the surgery. These issues are critical as they directly influence postoperative prosthesis alignment and patient-reported outcome measures (PROMs), which are key indicators of the procedure's success and patient satisfaction.[2,3]

Innovative techniques and advanced guiding tools have been developed to address these surgical challenges. Among these, robotic-assisted total knee arthroplasty (RATKA) has gained prominence. RATKA incorporates sophisticated navigation technology to enhance the precision of preoperative planning. This technology facilitates accurate localization of the hip center, guides precise bone cutting, and enables comprehensive evaluation of soft tissue and overall tension. By improving these critical surgical steps, RATKA aims to enhance the accuracy of prosthesis placement and potentially improve patient outcomes.[4,5]

Numerous observational studies and systematic reviews have highlighted the benefits of RATKA over COTKA. These studies suggest that RATKA improves the accuracy of prosthesis placement and positively impacts certain PROMs. Despite these promising findings, the evidence primarily stems from observational studies, which may be limited by inherent biases.[6] In the past four years, several randomized controlled trials (RCTs) have been conducted to provide more robust evidence by directly comparing RATKA with COTKA.

Despite the increasing number of studies, there has been no comprehensive systematic review and meta-analysis specifically focusing on these trials. Systematic reviews and meta-analyses are crucial as they provide higher quality evidence and more reliable pooled estimates. Such reviews can offer greater confidence in the findings and potentially validate the results observed in observational studies. Therefore, we conducted this systematic review to evaluate whether RATKA could improve clinical, functional, and radiological outcomes compared with COTKA in adult patients with primary knee OA.

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METHODS

Protocol

The Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) 2020 standards were scrupulously followed by the work's author. The purpose of this was to make sure the study satisfied all the requirements. The chosen technique was carefully designed to ensure the accuracy and dependability of the investigation's findings.

Criteria for Eligibility

This systematic review was done to evaluate whether RATKA could improve clinical, functional, and radiological outcomes compared with COTKA in adult patients with primary knee OA based on literatures of the last 10 years. This study meticulously analyzed data on literatures to provide insights and enhance patient treatment strategies. The primary objective of this paper is to highlight the collective significance of the identified key points.

Inclusion criteria for this study entail: 1) Papers must be in English, and 2) Papers must have been published between 2014 and 2024. Exclusion criteria comprise: 1) Editorials; 2) Submissions without a DOI; 3) Previously published review articles; and 4) Duplicate entries in journals.

Search Strategy

The keywords used for this research are robot-assisted total knee arthoplasty, conventional total knee arthoplasty, clinical outcomes, radiological outcomes. The Boolean MeSH keywords inputted on databases for this research are: ("(robot-assisted total knee arthroplasty OR RATKA) AND (conventional total knee arthroplasty OR COTKA) AND (clinical outcomes) AND (radiological outcomes)").

Data retrieval

The authors assessed the studies by reviewing their abstracts and titles to determine their eligibility, selecting relevant ones based on their adherence to the inclusion criteria, which aligned with the article's objectives. A consistent trend observed across multiple studies led to a conclusive result. The chosen submissions had to meet the eligibility criteria of being in English and a full-text.

This systematic review exclusively incorporated literature that met all predefined inclusion criteria and directly pertained to the investigated topic. Studies failing to meet these criteria were systematically excluded, and their findings were not considered. Subsequent analysis examined various details uncovered during the research process, including titles, authors, publication dates, locations, study methodologies, and parameters.

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Quality Assessment and Data Synthesis

Each author independently evaluated the research presented in the title and abstract of the publication to determine which ones merited further exploration. The subsequent stage involved assessing all articles that met the predefined criteria for inclusion in the review. Decisions on including articles in the review were based on the findings uncovered during this evaluation process. This criterion aimed to streamline the paper selection process for further assessment, facilitating a comprehensive discussion of previous investigations and the factors that made them suitable for inclusion in the review.

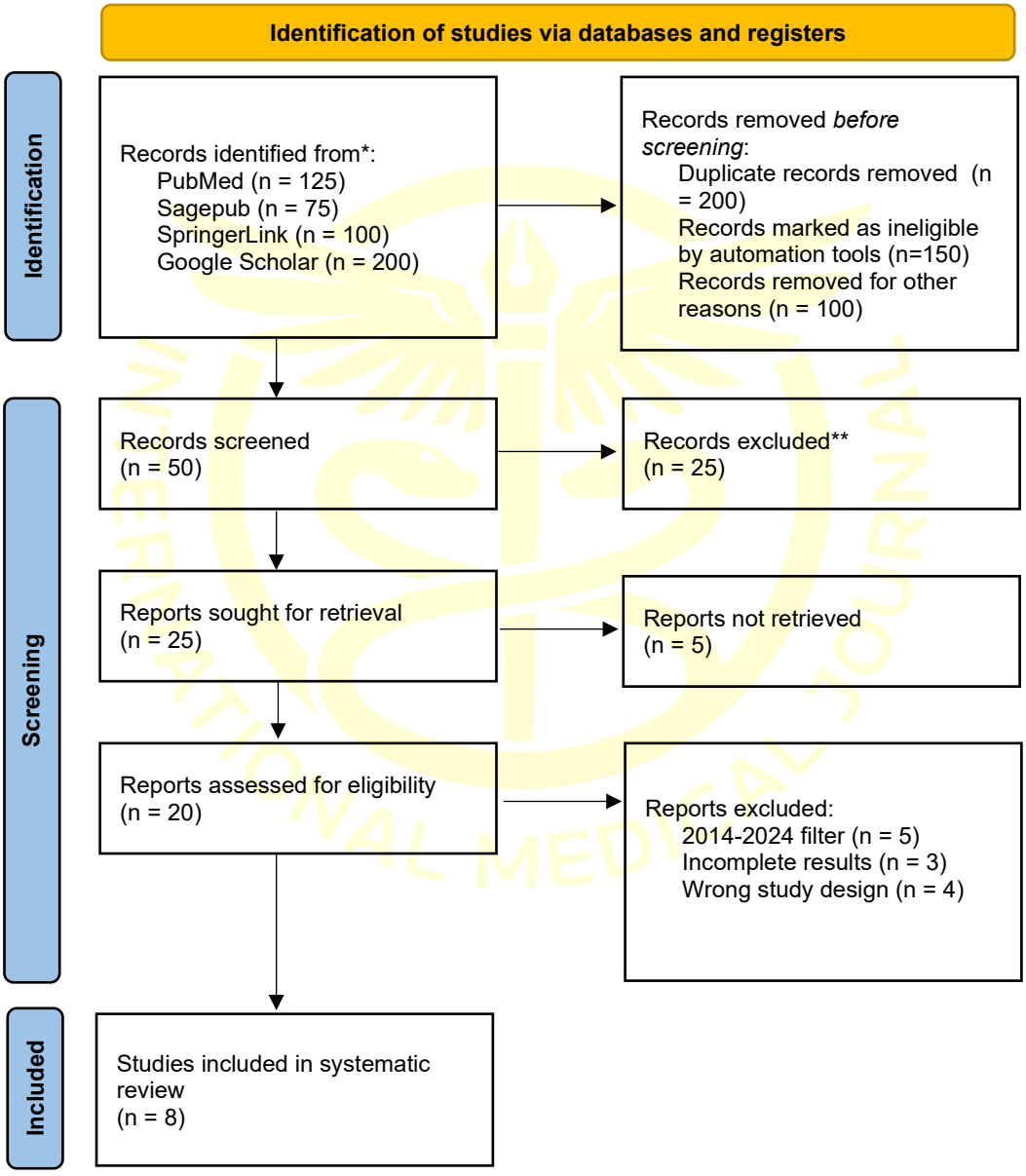


Figure 1. Article search flow chart

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RESULT

The initial number of articles retrieved from online databases (PubMed, SagePub, SpringerLink, and Google Scholar) is 500 articles. After conducting three levels of screening, ten articles that directly relate to the current systematic review have been chosen for further assessment through full-text reading and analysis. Table 1 presents the selected literature included in this analysis.

In this systematic review, a total of 2,003 samples were analyzed across diverse populations and geographic regions. The summarized studies encompass a diverse global distribution, including Singapore, Korea, the UK, Thailand, India, China, and Russia, highlighting widespread interest and adoption of robotic-assisted total knee arthroplasty (RATKA) across different regions. Key findings indicate that RATKA generally offers superior alignment accuracy and reduced postoperative complications compared to conventional TKA (COTKA).

Table 1. The literature included in this study

No	Author	Origin	Method	Sample	Result
1.	Liow, et al.[7] (2017)	Singapore	RCT	60 knees	Both robotic-assisted and conventional total knee arthroplasty (TKA) showed significant improvements in most functional outcome scores after two years. The robotic-assisted group had a higher complication rate but tended to have better SF-36 quality of life scores, with significant differences in SF-36 vitality ($p = 0.03$) and role emotional ($p = 0.02$). Additionally, a larger proportion of patients in the robotic-assisted group achieved the minimum clinically important difference (MCID) for SF-36 vitality (48.4% vs. 13.8%, $p = 0.009$). There were no significant differences between the groups in the Knee Society Score (KSS), Oxford Knee Score (OKS), or satisfaction and expectation rates.
2.	Kim, et al.[8] (2020)	Korea	RCT	1406 patients	At the latest follow-up, clinical and radiographic parameters were similar between robotic-assisted and conventional total knee arthroplasty (TKA) groups. The Knee Society knee scores, Knee Society function scores, WOMAC

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					scores, range of knee motion, and UCLA patient activity scores showed no significant differences between the groups after a mean of 13 years. Radiographic measurements, including femorotibial angle, femoral and tibial component positions, joint line, and posterior femoral condylar offset, were also comparable. The aseptic loosening rate was 2% in both groups, with a 15-year Kaplan-Meier survivorship of 98% for TKA components in each group. Complication rates, including superficial infections and motion limitations, were equally low in both groups, with no deep infections reported.
3.	Kayani, et al.[9] (2021)	UK	Prospective RCT	30 patients	Patients undergoing conventional and robotic-assisted total knee arthroplasty (TKA) experienced similar changes in systemic inflammatory and localized thermal responses postoperatively at six hours, day 1, day 2, and day 28. However, at day 7, robotic TKA showed significantly lower levels of interleukin-6, tumor necrosis factor-α, ESR, CRP, lactate dehydrogenase, and creatine kinase compared to conventional TKA. Additionally, robotic TKA better preserved the periarticular soft tissue envelope and reduced femoral and tibial bone trauma. It also significantly improved the accuracy of achieving planned limb alignment and component positioning for both the femur and tibia.
4.	Thiengwittayaporn, et al.[10] (2021)	Thailand	Prospective RCT	152 patients	Robotic-assisted total knee arthroplasty (RATKA) demonstrated significantly better accuracy in knee alignment and component

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					positioning compared to conventional TKA. Specifically, RATKA had fewer hip-knee-ankle axis and implant position outliers, with 94.7% of patients achieving overall mechanical alignment within 3° of a neutral mechanical axis. Changes in posterior condylar offset and joint line were also significantly lower in the RATKA group. Additionally, a learning curve of seven cases was identified for optimizing operative time with RATKA.
5.	Vaidya, et al.[11] (2022)	India	RCT	60 patients	In the conventional TKA (C-TKA) group, mechanical axis deviation greater than 3° occurred in eight cases (28.5%), whereas in the robotic-assisted TKA (RATKA) group, it was observed in only one case (3.1%) ($p = 0.019$). Joint line deviation was notably higher in the C-TKA group at 3.5 mm compared to 0.9 mm in the RATKA group ($p < 0.001$), a statistically significant difference. However, whether this 2.6 mm discrepancy in joint line elevation between C-TKA and RATKA influences clinical outcomes such as knee kinematics and flexion requires further investigation.
6.	Xu, et al.[12] (2022)	China	RCT	77 patients	Robotic-assisted total knee arthroplasty (RATKA) had longer operation times (154.3 vs 115.2 min, $p < 0.001$) compared to conventional TKA (COTKA), with similar blood loss. Both groups showed improved knee function post-surgery ($p < 0.05$), and RATKA had fewer outliers in lateral tibial component angle (3.0% vs 29.4%, $p = 0.003$) and lower NLR on day 1 (9.9 vs 12.7, $p = 0.024$).

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7.	Li, et al.[13] (2022)	China	RCT	150 patients	Patients who underwent robotic-assisted total knee arthroplasty (RATKA) showed significantly better postoperative mean hip-knee-ankle (HKA) alignment angles compared to conventional TKA (3.017° ± 2.735° varus vs. 1.801° ± 1.608° varus). The RATKA group also had a higher alignment rate achieving a mechanical axis within 3° varus or valgus (81.2%) compared to the conventional TKA group (63.5%). Both RATKA and conventional TKA groups demonstrated similar improvements in knee flexion and functional recovery as measured by WOMAC score, Hospital for Special Surgery (HSS) score, SF-36 score, and Knee Society Score (KSS).
8.	Lychagin, et al.[14] (2022)	Russia	Prospective study	68 patients	Group A exhibits stronger post-operative pain syndrome by 7.9% on the 1st day post-surgery, but a 14.3% lower pain syndrome by the 5th day. Range of motion (ROM) is notably improved in Group A by 16% at 3 months and by 10% at 1 year compared to Group B. Implant positioning accuracy is 30% better in Group A. There are no significant differences in Oxford Knee Score (OKS) and WOMAC scales between the groups. Group A demonstrates 13.5% better results in restoring normal gait compared to Group B.

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DISCUSSION

Total knee arthroplasty (TKA) remains a cornerstone in the management of advanced knee osteoarthritis, aiming to alleviate pain and improve function. The advent of robotic-assisted TKA (RATKA) has introduced technological advancements purported to enhance surgical precision and outcomes compared to conventional TKA (COTKA). This systematic review synthesizes findings from recent randomized controlled trials (RCTs) and prospective studies across diverse geographic regions to compare the clinical and radiological outcomes between RATKA and COTKA.

The reviewed studies spanned diverse geographical regions, including Asia (Singapore, Korea, Thailand, China, India) and Europe (UK, Russia). This global distribution underscores the widespread interest and adoption of RATKA technology, albeit with variations in healthcare settings and patient demographics. Regional differences in surgical practices, healthcare infrastructure, and patient selection criteria may influence outcomes and complication rates, warranting consideration in clinical decision-making and future research.

Across the studies reviewed, both RATKA and COTKA demonstrated significant improvements in clinical outcomes postoperatively. Studies by Liow et al. (2017), Kim et al. (2020), and Li et al. (2022) consistently reported comparable improvements in functional scores such as Knee Society Score (KSS), Oxford Knee Score (OKS), and WOMAC scores between the two techniques.[7,8,13] This suggests that while RATKA offers potential advantages in surgical precision and alignment, these benefits may not consistently translate into superior functional outcomes in terms of patient-reported measures compared to COTKA.[15,16]

RATKA exhibited mixed findings regarding complication rates compared to COTKA. Liow et al. (2017) noted a higher complication rate in the RATKA group but reported better SF-36 quality of life scores, particularly in vitality and role emotional domains.[7] Conversely, studies by Xu et al. (2022) and Kayani et al. (2021) highlighted reduced inflammatory responses and preserved soft tissue envelope with RATKA, potentially contributing to enhanced recovery and reduced perioperative morbidity.[9,12] However, consistent evidence regarding specific complication rates such as infection or deep vein thrombosis did not significantly differ between RATKA and COTKA groups across the studies reviewed.[17]

Radiological outcomes favored RATKA in terms of alignment accuracy and implant positioning. Thiengwittayaporn et al. (2021) and Li et al. (2022) reported significantly better mechanical alignment within 3° varus or valgus in RATKA groups compared to COTKA.[10,13] This precision was further supported by fewer outliers in hip-knee-ankle axis and implant positions in RATKA, as noted by Thiengwittayaporn et al. (2021) and Xu et al. (2022).[10,12] Improved alignment in RATKA is critical as it potentially correlates with long-term prosthesis survival and functional outcomes, although the clinical significance of these radiological differences requires further investigation.[18]

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Operative time was consistently longer in RATKA compared to COTKA, a finding corroborated by Xu et al. (2022).[12] The extended surgical duration in RATKA may reflect the additional time required for preoperative planning and intraoperative navigation.[19] Moreover, studies such as Thiengwittayaporn et al. (2021) identified a learning curve for RATKA, typically requiring several cases to optimize procedural efficiency and reduce operative time.[10] Despite longer operative times, RATKA demonstrated comparable blood loss profiles to COTKA across the studies reviewed, suggesting that technological advancements may mitigate some intraoperative risks.[20]

Despite the valuable insights provided by the included studies, several limitations must be acknowledged. Variability in study design, sample sizes, and follow-up durations may introduce heterogeneity in the pooled analyses. Additionally, the definition and reporting of clinical outcomes and complications varied among studies, potentially impacting the robustness of comparative analyses. Future research should focus on standardized outcome measures, longer-term follow-up, and large-scale multicenter trials to further elucidate the comparative effectiveness and cost-effectiveness of RATKA versus COTKA.

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