Efficacy and safety of robotic-assisted knee reconstruction: a systematic review and meta-analysis

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Abstract. – OBJECTIVE: Robotic-assisted surgery is increasingly being utilized in hip and knee reconstruction. However, the relative efficacy and safety of robotic-assisted total knee replacement (RATKR) compared to traditional surgery remained uncertain. This study aimed to systematically review the current literature comparing the outcomes of RATKR to traditional procedures.

MATERIALS AND METHODS: Comprehensive literature searches were conducted in major databases to identify studies comparing RATKR with traditional surgeries. The primary outcomes were functional scores and post-operative complications. Pooled mean differences (MDs) with 95% confidence intervals (CIs) were calculated using a random effects model.

RESULTS: A total of 12 studies were considered for inclusion. The pooled functional scores of The Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Knee Society Score (KSS), hospital for Special Surgery (HSS) score, visual analogue score (VAS) pain score showed no significant differences between the two groups (MD = -0.99, 95% CI -2.32 to 0.34, *p*-value = 0.14). The subgroup analysis for hip and knee reconstructions also revealed no significant difference in terms of functional scores. However, for post-operative complications, while there was no significant difference in terms of blood loss (MD = -1.62, 95% CI -4.42 to 1.17, *p*-value = 0.25), the readmission rates were significantly higher in the RATKR group (MD = 0.94, 95% CI 0.77 to 1.11, *p*-value < 0.00001). The overall heterogeneity was extremely high (I^2 = 93%), particularly in the analyses of post-operative complications.

CONCLUSIONS: The findings suggested that robotic-assisted knee reconstruction did not significantly improve functional outcomes compared to traditional surgery. The safety profile was similar except for a higher readmission rate following RATKR. Given the high heterogeneity, further large-scale, well-designed, randomized controlled trials are needed to conclusively determine the efficacy and safety of robotic-assisted hip and knee reconstruction.

Key Words:

System review, outcome assessment, meta-analysis, Comparative study, Robotic-assisted surgery, Knee reconstruction, Functional scores, Post-operative complications.

Introduction

Orthopedic surgery is one of the many surgical specialties continuously integrated with the rapidly developing medical technology[1]. The advent of robotic-assisted surgery, particularly robotic-assisted total knee arthroplasty (RATKA), has been a noteworthy development in this field. The goal of RATKA is to improve surgical accuracy and precision, which could improve patient outcomes[2]. Even while RATKA is becoming increasingly popular, opinions on its safety and effectiveness in comparison to traditional total knee arthroplasty (TKA) are still divided[3].

For end-stage knee osteoarthritis, TKA is a popular and effective treatment that aims to lessen discomfort and restore function[4]. However, the alignment and placement of the prosthesis – both of which are heavily reliant on the surgeon's knowledge and experience – are crucial to the efficacy of TKA. More standardization made possible by the advancement of robotically assisted technology may lead to better results from these surgeries[5].

The goal of using RATKR to improve bone preparation accuracy is to reduce deviations and lengthen the lifespan of prostheses. In the context of TKA, less polyethylene degradation and fewer correction procedures have been linked to an ideal mechanical axis alignment[6]. Research indicates that 94% of robotic total knee arthroplasty cases obtained adequate flexion and extension gaps, in contrast to 80% of traditional TKA cases[5,7,8]. Using the gadget software to assess gaps, surgeons can accurately adjust soft tissue balance

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thanks to robotic technology. This procedure can be performed either before or after bone incisions[9]. Good outcomes from complete knee arthroplasties depend on several factors, such as soft tissue preservation, flexion-extension gap balancing, optimal prosthesis insertion, and suitable ligament tension. Many of these components depend on factors unique to surgeons, whose training and experience may differ greatly[7,8]. Soft tissue balance and bone excision are part of traditional TKA therapies. Typical drawbacks include a lack of repeatability, difficulty in accurately adjusting implant location, and a potential for unintentional soft tissue injury[10]. An unsatisfactory outcome for the patient could arise from inaccurate prosthesis placement or poor gap balancing, which can lead to increased instability, a longer recovery period, more rigorous rehabilitation, and a shorter implant lifespan[11].

With RATKA, specialized software converts anatomical data into a three-dimensional virtual reconstruction of the joint. This information is often obtained by intraoperative tibia and femur mapping or preoperative CT scans[11]. Based on each patient's unique anatomy, surgeons can use this 3D model to plan the optimal bone covering, limb alignment, implant placement, and bone cutting. The intraoperative robotic tool lessens accidental soft tissue and bone damage[12].

RATKA outcomes have been the subject of numerous studies, yielding information on readmission rates, complications, functional scores, and surgical precision[5,7-11]. The findings, however, have been inconsistent; although some studies have found no appreciable difference between RATKA and regular TKA, others have reported improved effects[12]. These discrepancies necessitate a full synthesis of the available data to give a better understanding of the efficacy and safety of RATKA. Consequently, the goal of this systematic review and meta-analysis was to assess RATKA's safety and efficacy in relation to conventional TKA or controls. Through synthesizing the results of several outstanding studies, this study sought to provide a more definitive answer to this clinically relevant question.

Materials and Methods

Review Design

This systematic review and meta-analysis adhered to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology[13]. Figure 1 illustrates the findings of the identification part of the process, which began with thorough literature searches across many databases to locate relevant studies.

For this review, the PECO (Population, Intervention, Comparator, Outcomes) process was very clear and acted as a guide for the entire study. The demographic of interest was patients who had undergone knee reconstruction surgery. The intervention being evaluated was called RATKR, and the manual or traditional methods of knee repair were used to make the comparison. The primary outcomes that were considered were the functional scores (WOMAC, VAS, KSS, and HSS) that were acquired following surgery. Secondary outcomes included readmission rates, surgical precision as evidenced by component placement and postoperative alignment, and postoperative complications.

Database Search Strategy

A thorough search strategy was used across eight different databases, including PubMed, Embase, Cochrane Library, Web of Science, Scopus, CINAHL, PsycINFO, and Google Scholar, for this review. Boolean operators, Medical Subject Headings (MeSH) phrases, and combinations of free-text terms formed the basis of the exhaustive search technique, and to make sure that the articles that were retrieved were pertinent to the research issue, the Boolean operator "AND" was utilized to merge two distinct concepts.

Selection Criterion

The purpose of the inclusion criteria was to include research that provide the most direct and pertinent data available on the subject. Studies that evaluated the results of RATKA with traditional manual procedures were specifically included if they were case-control, cohort, or randomized controlled trials (RCTs). All human subjects who had knee reconstruction surgery were required for the study, irrespective of their age, sex, or race. Additionally, at least one of the predetermined outcomes of interest, such as functional scores, postoperative complications, readmission rates, and surgical precision as shown by component placement and postoperative alignment, had to be covered by the included studies.

Conversely, the exclusion criteria were created to remove studies that could add bias or skew the results. Research that fit the following criteria was specifically disqualified: case reports, case series, editorials, reviews, or non-comparative research. Studies that used different kinds of ro-

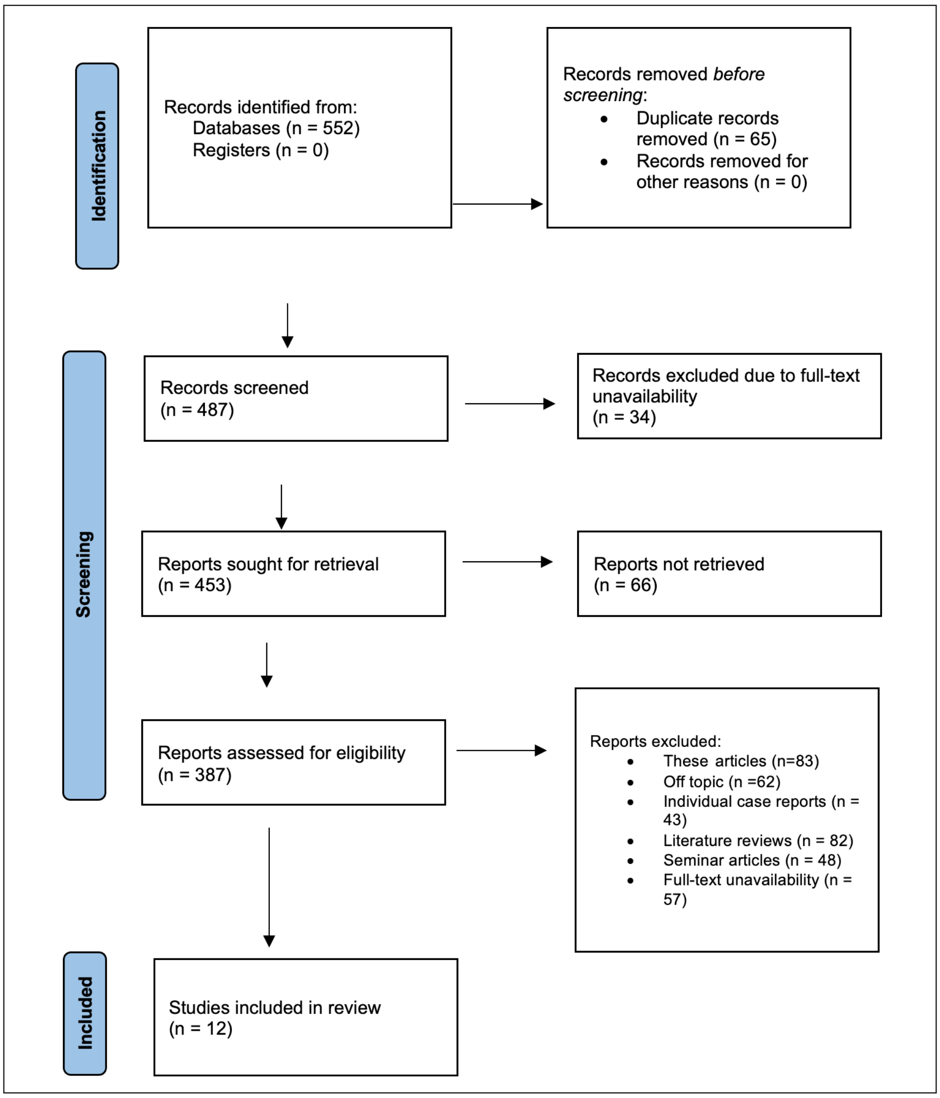

Figure 1. PRISMA protocol representation for the review.

botic systems or involved different kinds of knee surgery were excluded. Excluded from consideration were studies that either did not report on any relevant outcomes or did not supply enough data for the extraction. Lastly, research published in a language other than English was disqualified because of the possibility of translation bias.

Data Extraction Schematics

Two separate reviewers extracted the data using a standardized data extraction form after the pertinent publications were found through screening and eligibility evaluation. This form was created to record all the pertinent data regarding the study's attributes, such as the author(s), publication year, study design, nation, sample size, demographics of the participants (such as age, sex, and baseline disease severity), intervention and comparator details, follow-up period, and the desired outcomes and their measurements at various intervals. To guarantee correctness, the two reviewers cross-checked the extracted data. During this procedure, any differences among the reviewers were settled by discussion or, if required, by consulting with a third reviewer.

The kappa statistic was employed to evaluate the interrater reliability of the data extraction procedure. This statistic assesses the degree of agreement between two raters over random variation. The kappa statistic in this review was computed to be 0.86, suggesting that the two reviewers had a high degree of agreement. The high kappa value offered comfort regarding the uniformity in the interpretation of the included studies and the dependability of the data extraction procedure.

Bias Assessment

The Cochrane's Risk of Bias 2.0 tool[14] (RoB 2.0, available at: https://www.riskofbias.info/welcome/rob-2-0-tool) was used to perform a thorough bias assessment across the papers included in this review. This tool offers a comprehensive framework to investigate multiple domains that might introduce bias and is specifically intended to evaluate the risk of bias in randomized trials.

Statistical Analysis

The Review Manager RevMan 5.3 software Version 5.3. (Copenhagen, Denmark) from the Cochrane Collaboration was used to conduct the meta-analysis and generate forest plots for this review. The measures of RATKA efficacy and safety across several domains were the key findings of the meta-analysis. The means of the outcomes for the RATKA and control groups were directly compared due to the presentation of these measurements as mean differences (MD) with 95% confidence intervals (CIs). A random-effects (RE) model was selected for the meta-analysis because of the anticipated heterogeneity across the included studies regarding their participant characteristics, methodological approaches, and outcome measures. RevMan was used to create forest plots and showed the overall effect size and its 95% CI in addition to the MD and 95% CI for each research. The I^2 statistic was used to measure the heterogeneity among the included studies. A high degree of heterogeneity was indicated by high values of I^2 (above 50%), which was further investigated where necessary using sensitivity analyses or subgroup analyses. For statistical purposes, a p-value < 0.05 was considered significant.

Results

Study Selection Procedure

552 possible studies were retrieved from different databases to start the identification process. After 65 duplicate entries were removed from the original pool of recognized studies, 487 records were left for screening. In the screening stage, 453 reports were searched for full-text retrieval after 34 records were eliminated based on the title and abstract. 387 full-text publications were evaluated for eligibility after 66 reports could not be downloaded. These 387 reports underwent a thorough investigation as part of the eligibility screening process. At this point, a number of exclusion criteria were implemented. 43 case reports, 48 seminar pieces, 57 publications whose full texts were unavailable, 62 studies that did not meet the stated goals, 82 literature reviews, and 83 theses articles were eliminated. To make sure the studies included in the review were unique research publications that were strictly relevant to the subject, these exclusion criteria were used. Twelve articles[15-26] made it through these stringent selection and exclusion procedures and were added to the systematic review and meta-analysis for quantitative and qualitative analysis.

Evaluated Demographic Variable

The trial years and regions ranged from 2007 to 2023, and they were carried out in a number of countries, including the US, China, Singapore, South Korea, and India[15-26]. This global perspective, which considers healthcare, cultural differences, and demographics, allows for a deeper understanding of the issue. Prospective, retrospective, and randomized controlled trials were employed in these studies[15-26]. Significant differences in sample sizes were seen among the studies; 287 was the largest cohort, and 60 was the smallest[15,19]. Sample size can have an impact on a study's statistical power; larger samples typically result in more precise estimates of population parameters.

The gender ratios in the research varied as well[15-26]. Some studies[18,21,22] included information on the ratio of male to female participants, while others did not[15-17,23-25]. The average participant age in each study was within the senior age range, indicating that most participants were older individuals[15-26]. The average age of the participants was determined to be 62.2, the lowest being 62.2, and the greatest being 70.75, throughout all investigations. Follow-ups were spaced out between three and sixty-five months[15-26]. The length of the follow-up period may have an effect on how well a study captures longer-term outcomes and issues. Remarkably, one study[25] did not specify the duration of the follow-up.

RATKR-Related Parameters Evaluated

Table I compiles the extensive spectrum of RATKR-related parameters[15-26]. These comprised

Table I. TKA-related assessments and their observed inferences.

Study ID	Groups assessed	Parameters assessed	RATKA-related outcome observed	Overall inference observed
Blum et al[15]	Not specified	KOOS, KSS, expectation fulfilment, satisfaction	- KOOS and KSS measured preoperatively and at 3M, 6M, 1Y, and 2Y postoperatively - Expectation fulfilment assessed pre-operatively and at 3M and 6M post TKA - Satisfaction compared at 1Y and 2Y post TKA.	Higher satisfaction scores related to expectation fulfilment at 1Y and 2Y.
Duan et al[16]	Manual *vs.* Robotic	Outcome accuracy, hip-knee-ankle angle, pre-op scores	- Defining beneficial outcome as a postoperative improvement of the functional Knee Society Score (fKSS) of more than 10 points, 3 months after RA-TKA - Assessing preoperative hip-knee-ankle angle deviation, preoperative VAS score, preoperative fKSS score, preoperative ROM.	High consistency and predictive accuracy in outcomes.
Held et al[17]	Manual *vs.* Robotic	Demographics, intra-/ post-op data, PROMs, WOMAC, SF-12, EBL	- Basic demographic information, intraoperative and postoperative data, and PROMs collected and recorded preoperatively, at 3-, 12- and 24-months postoperatively - ROM, EBL, surgical duration, and complications also collected.	Similar post-op outcomes; robotic-assisted had longer surgery and more blood loss.
Liow et al[18]	Manual *vs.* Robotic	ROM, KSS, OKS, SF-36, satisfaction, MCID	- Differences in ROM, KSS knee and function scores, OKS, SF-36 subscale and summative analyzed - Patient satisfaction, fulfilment of expectations and the proportion attaining a MCID in KSS, OKS and SF-36 studied.	Robotic-assisted may have better quality of life; no difference in satisfaction.
Mitchell et al[19]	mTKA *vs.* raTKA	Demographics, complications, readmissions, outcomes	- LOS, morphine consumption, and PT visits compared - 30-day readmission rates assessed - Knee Injury and Osteoarthritis Outcome Score for Joint Replacement and the University of California at Los Angeles activity score compared at 1 year.	More post-op issues with manual TKA, no significant difference in 1Y activity scores.
Nam et al[20]	MAKO *vs.* Conventional	Mechanical axis, component positioning, liner thickness	- Post-operative radiographs used to evaluate mechanical axis and component positioning - Polyethylene liner thickness investigated.	Robotic-assisted achieved better alignment; no difference in liner thickness.
Park et al[21]	Manual *vs.* Robotic	Femoral/tibial angles, surgical accuracy	- The γ and δ angles in the lateral x-ray of the two groups were compared - Major complications reviewed.	Robotic-assisted offered better surgical accuracy, especially in knee angles.
Song et al[22]	Robotic *vs.* Manual	Radiographs, knee scores, ROM, surgery details, bleeding	- Radiographic results compared - Postoperative knee scores and ROMs analyzed - Operation times, skin incisions, and postoperative bleeding compared.	Robotic-assisted provided more accurate leg alignment; less bleeding, longer surgery.
Song et al[23]	Robotic *vs.* Conventional	ROM, WOMAC, HSS scores, axis alignment, gap balance	- Postoperative ROM, WOMAC scores, HSS knee scores compared - Mechanical axis alignment and flexion/extension gap balance assessed - Complications, postoperative drainage, and operative time compared.	Robotic-assisted reduced alignment outliers, took longer, less drainage.
Tian et al[24]	RAS *vs.* CON	Demographics, imaging, Knee Society score, ROM, HKA angle	- Postoperative malalignment of the mechanical axis compared - Preoperative HKA angle deviation, operation duration, and postoperative HKA angle outlier rate assessed - HKA angle deviation and CFCA deviation compared among patients with a preoperative HKA angle deviation ≥6°.	Better alignment in robotic-assisted, especially with pre-op deviations.
Vaidya et al[25]	C-TKA *vs.* RA-TKA	Axis/joint line deviation, prosthesis alignment	- Significant difference in mechanical axis deviation, joint line deviation, and coronal alignment of femoral and tibial prosthesis between the two groups - No significant difference in femoral component rotation on postoperative CT scan.	Lower axis and joint line deviation in robotic-assisted; impact on kinematics unknown.
Yuan et al[26]	RATKA *vs.* Traditional TKA	Surgery time, blood loss, VAS scores, ROM, WOMAC, HKA deviation	- Operation time, intraoperative blood loss, knee joint VAS resting and motion scores, ROM, KSS scores, and WOMAC pain, stiffness, and functional scores compared - HKA deviation, LTC, FFC, FTC, and LFC measured to evaluate lower limb alignment and prosthesis position - Gait measured 3 months after operation.	Robotic-assisted had longer surgery but better post-op gait at 3 months.

KOOS: Knee injury and Osteoarthritis Outcome Score; KSS: New Knee Society Score; mTKA: manual Total Knee Arthroplasty; fKSS: functional Knee Society Score; PROMs: Patient-Reported Outcome Measures; WOMAC : Western Ontario and McMaster Universities Osteoarthritis Index; SF-12: 12- item short form survey; Mtka: manual Total Knee Arthroplasty; raTKA: robotic-assisted Total Knee Arthroplasty; EBL: Estimated Blood Loss; ROM: Range of Motion; oks: Oxford Knee Score; SF-36: 36-Item Short Form Health Survey score; MCID: Minimal Clinically Important Difference; HSS: Hospital for Special Surgery; HKA: Hip-Knee-Ankle; RAS: robotic-assisted system group; CON: conventional techniques group; CFCA: coronal femoral component angle; c-TKA: Conventional total knee arthroplasty; VAS: Visual Analogue Scale; LTC: Lateral Tibial Component; FFC: Femoral Flexion Component; FTC: Femoral Tibial Component; LFC: Lateral Femoral Component operation data, patient-reported outcome measures (PROMs), and objective clinical results, among other things. Two objective criteria that were evaluated at different times following surgery were Knee injury and Osteoarthritis Outcome Score (KOOS) and New Knee Society Score (KSS). After surgery, various subjective metrics were assessed, including patient satisfaction and expectation fulfillment. The main focus of Duan et al[16] evaluation was the concept of a "beneficial outcome", which is defined as a postoperative functional knee society score (fKSS) improvement above 10 points three months post-RATKR. They also measured the hip-knee-ankle angle deviation, preoperative range of motion (ROM), preoperative fKSS score, and preoperative Visual Analogue Scale (VAS) score. Held et al[17] adopted a comprehensive strategy, collecting demographic data as well as data from intraoperative and postoperative operations. They also kept records of the length of the procedure, complications, estimated blood loss (EBL), and range of motion. Additionally, they kept an eye on PROMs three, twelve, and twenty-four months after surgery. Liow et al[18] assessed variances in range of motion, KSS knee and function scores, the Oxford knee score (OKS), the 36-item short-form health survey score (SF-36) subscale, and summative scores. They also looked at expectation fulfillment, patient satisfaction, and the proportion of KSS, OKS, and SF-36 scores that were able to obtain a minimal clinically important difference (MCID). Mitchell et al[19] examined patient demographics, complications, readmission rates, and clinical and patient-reported outcomes. They also assessed the length of hospital stay, morphine consumption, physical therapy visits, and 30-day readmission rates.

Nam et al[20] used postoperative radiography to measure the polyethylene liner's thickness as well as the mechanical axis and component position. Park and Lee[21] analyzed the main issues and contrasted the δ (tibial) and γ (femoral flexion) angles in lateral X-rays. Song et al[22] and Song et al[23] conducted comparative analyses of radiographic results, postoperative knee scores, range of motion, operating times, skin incisions, and postoperative hemorrhage. Furthermore, Song et al[23] assessed mechanical axis alignment, flexion/extension gap balancing, postoperative drainage, operative time, and complications. Tian et al[24] examined postoperative mechanical axis malalignment, preoperative HKA angle deviation, operation length, and postoperative HKA angle outlier rate. Vaidya et al[25] observed substantial alterations in the coronal alignment, joint line deviation, and mechanical axis deviation of the femoral and tibial prosthesis but no significant difference in the rotation of the femoral component on postoperative CT scans. Yuan et al[26] compared the length of the operation, blood loss during the procedure, knee joint VAS resting and motion ratings, range of motion, KSS scores, WOMAC pain, stiffness, and functional scores. To evaluate the prosthesis position and lower limb alignment, they additionally assessed hip-knee-ankle (HKA) deviation, lateral tibial component (LTC), femoral flexion component (FFC), and lateral femoral component (LFC).

Overall Conclusions Drawn

RATKR's efficacy: Blum et al[15] emphasized the importance of patient expectations for satisfaction following RATKR. Sports and recreation were an exception, even though there were no appreciable changes in postoperative KOOS outcomes compared to the Function and Outcomes Research for Comparative Effectiveness in Total Joint Replacement (FORCE-TJR) database. The ability of machine learning to predict RATKR outcomes with high accuracy and consistency was demonstrated by Duan et al[16]. Following two years of TKA, Liow et al[18] observed improvements in most functional outcome scores in both robotic-assisted and conventional TKA. In the SF-36 Quality of Life measurements, the robotic-assisted group trended towards higher scores, indicating similar clinical results between the two surgeries. According to Mitchell et al[19], clinical outcomes at one year were not significantly different between manual Total Knee Arthroplasty (mTKA) and RATKR, even though mTKA required more resources. The utilization of robotic systems has been associated with greater accuracy in component placement and postoperative alignment, as reported in selected studies[20-25]. These findings suggest increased surgical precision. In gait analysis, Yuan et al[26] noted that RATKR might be better at obtaining greater flexion and extension angles.

RATKR safety: Held et al[17] did not find any noteworthy variations in PROMs and postoperative complications among cohorts. Nonetheless, they pointed out that RATKR had considerably higher projected blood loss and longer surgery times. In patients having manual TKA as opposed to RATKR, Mitchell et al[19] observed longer lengths of stay, more morphine usage, more physical therapy sessions, and higher 30-day readmission rates. In robotically assisted surgeries, Song et al[22] and Song et al[23] saw reduced postoperative hemorrhage but longer operating times and wider skin incisions. The RATKR group showed better alignment precision, according to Tian et al[24], but at a price of noticeably longer operation times. While the RATKR group had lengthier operation times, Yuan et al[26] found comparable intraoperative blood loss between the RATKR and standard TKA groups.

Statistics Regarding the Effectiveness of RATKR

The forest plot in Figure 2 compares the effectiveness of RATKR and control over a number of clinical metrics, including VAS, WOMAC, KSS, and HSS scores. These metrics are frequently employed to assess patient outcomes in the wake of knee replacement surgery. The overall effect size across all measures was -0.99 (95% CI -2.32 to 0.34); *p*-value = 0.14 indicated this was not statistically significant. With an I^2 = 97% overall heterogeneity, all the studies' effect sizes varied greatly from one another. Furthermore, *p*-value = 0.64 showed no significant variation between subgroups, suggesting that the effect sizes were not significantly different amongst the various scoring techniques.

The MD for HSS scores was -0.58, with a 95% confidence interval spanning from -1.58 to 0.43

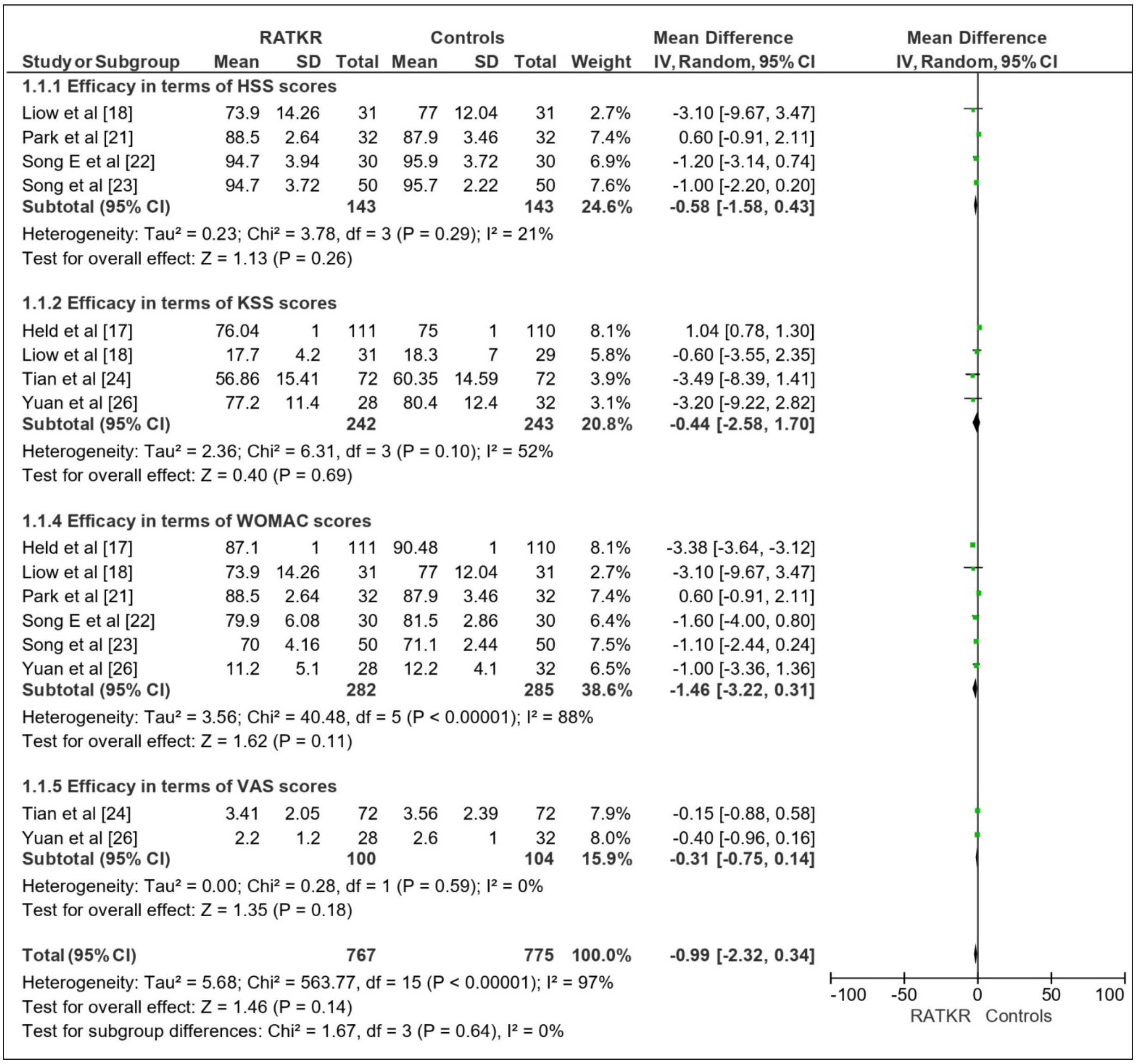

Figure 2. Efficacy of TKR across different patient-related outcomes.

across studies. p-value = 0.26 indicates no statistically significant difference in the HSS scores between the RATKR and control groups. With an I^2 of 21%, the heterogeneity was moderate, meaning that the effect sizes of the studies in this category varied only slightly.

The MD for KSS scores was -0.44 (95% CI -2.58 to 1.70) and did not reach statistical significance (p-value = 0.69), indicating that the KSS outcomes for the two groups were comparable. This time, there was more heterogeneity (I^2 = 52%), which suggests significant difference between trials.

The WOMAC scores indicated similar efficacy for RATKR and control. They revealed an MD of -1.46 (95% CI, -3.22 to 0.31), which was not statistically significant (p-value = 0.11). The high heterogeneity (I^2 = 88%) indicated significant differences in the impact sizes among these trials.

The MD of the VAS ratings was -0.31 (95% CI -0.75 to 0.14), showing similar pain levels in both groups. However, the result was not statistically significant (p-value = 0.18). With an I^2 = 0% heterogeneity, there was little difference between the investigations.

Statistics Regarding the Effectiveness of RATKR

The forest plot in Figure 3 evaluates the safety of RATKR in terms of problems that may arise after surgery. The complications are divided into two categories: readmission rates and blood loss (measured in liters). It was not statistically significant (p-value = 0.14), but the total MD for all measures was 0.36 (95% CI -0.12 to 0.83). With an I^2 = 93% overall heterogeneity, all the studies' impact sizes varied significantly from one another. Furthermore, significant variations were seen between subgroups (p-value = 0.07), indicating a significant variation in effect sizes between the two types of problems.

Three trials were examined for problems related to blood loss following surgery. According to Held et al[17], there was no difference in blood loss between the two groups, with an MD of 0.50 liters and a 95% confidence interval of 0.50 to 0.50. An MD of -2.47 liters (95% CI -4.53 to -0.42) was observed by Song et al[22], indicating that the RATKR group had reduced blood loss. Similar to this, Song et al[23] found that the RATKR group had decreased blood loss, with an MD of -3.20 liters (95% CI -4.77 to -1.63). These studies combined mean blood loss was -1.62 liters [95% confidence interval (CI) -4.42 to 1.17], and p-value = 0.25 indicated that it was not statistically significant.

Held et al[17] and Mitchell et al[19] studies were examined for post-operative problems in terms of hospital readmission. The heterogeneity was remarkably high (I^2 = 93%), suggesting significant differences in effect magnitude across these studies. The results of the two studies indicated that the RATKR group had higher readmission rates, with positive MDs of 1.00 and 0.90, respectively, and 95% CIs that did not cross zero (0.74 to 1.26 and 0.68 to 1.12). p-value < 0.00001 indicates that the pooled MD for readmission was

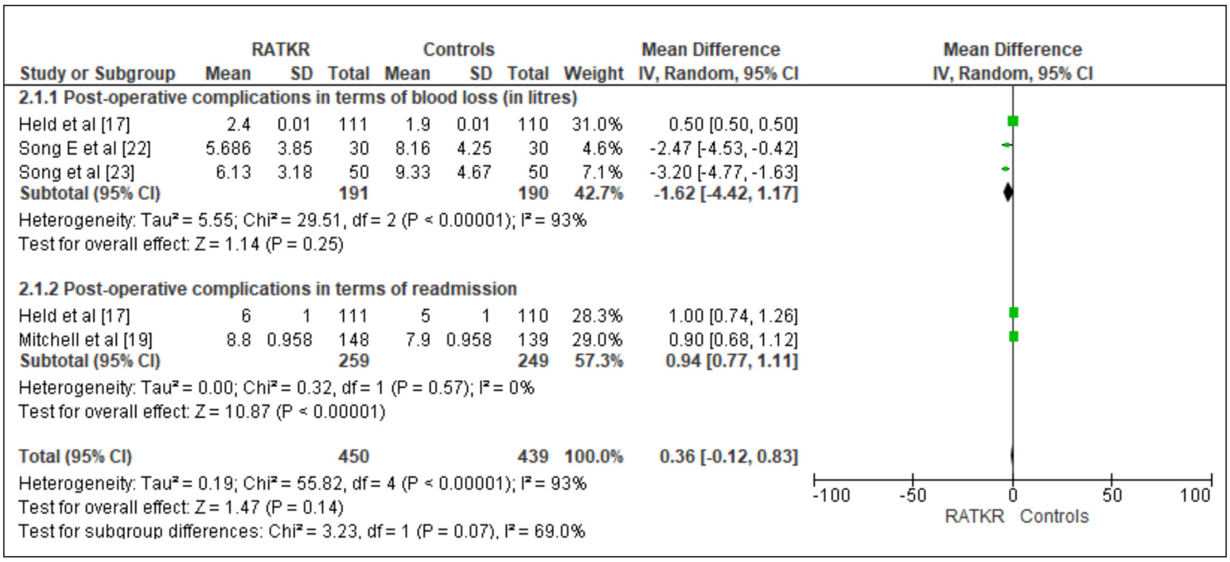

Figure 3. Safety of RATKR in terms of post-operative complications observed.

highly statistically significant, at 0.94 (95% CI 0.77 to 1.11). With an I^2 of 0%, the heterogeneity was null, meaning the effect sizes in these trials were all the same.

Discussion

It is possible to draw noticeable conclusions from the obtained results. On the one hand, RATKR's continued use and advancement as a successful knee replacement strategy is supported by the comparable functional outcomes between the technique and traditional procedures. However, considering the increased readmission rates linked to RATKR, more potent approaches are required to enhance operational safety and lower complications. The goal of research should be to determine the causes of these high readmission rates so that treatments can be created to reduce the hazards. Furthermore, the substantial degrees of heterogeneity shown in this study highlight the need for future research to describe results more rigorously and consistently in order to enable more accurate and legitimate comparisons. The prospective uses of cutting-edge technology, such as machine learning to forecast RATKR results were also made clear by this review, providing opportunities for risk stratification in knee replacement surgery and customized medicine. A higher quality of life could result from RATKR's improved alignment and potential for better flexion and extension angles, even if it needed more resources and longer operating hours. Nevertheless, methods to improve patient safety and speed up the surgical procedure are needed, given the extended operating hours and the possibility of increased blood loss.

The selected papers showed various outcomes with respect to efficacy. Blum et al[15] brought attention to the importance of pre-operative counseling by demonstrating how patient expectations affect post-RATKA satisfaction. The ability of machine learning to forecast RATKA results, as demonstrated by Duan et al[16], is encouraging for the application of personalized therapy in orthopedics. Similar clinical outcomes between RATKA and traditional TKA were reported by Liow et al[18] and Mitchell et al[19], indicating that RATKA may not always produce improved functional outcomes. For prosthesis survival and patient quality, however, RATKA improved surgical precision, which may have long-term advantages[20-25]. Better flexion and extension angles were seen in the gait study after RATKA by Yuan et al[26], which could suggest improved functional results.

Regarding safety, Held et al[17] did not find any appreciable variations between RATKA and conventional TKA in terms of patient-reported outcome measures (PROMs) or postoperative complications. Nonetheless, with RATKA, they saw longer operating times and more expected blood loss, raising questions regarding intraoperative dangers. Compared to patients who received RATKA, those who had manual TKA had 30-day readmissions, more physical therapy sessions, longer hospital stays, and greater rates of morphine use. These findings by Mitchell et al[19] imply that RATKA might be beneficial after surgery. The trade-off between surgical invasiveness and precision was highlighted by Song et al[22] and Song et al[23], who discovered that RATKA resulted in longer operating periods and wider skin incisions but less bleeding after surgery. Longer operation times employing RATKA were also noted by Tian et al[24] and Yuan et al[26], suggesting that more optimization of the robotic-assisted surgical technique is required.

Yoo et al[27] concentrated on the results of patients who underwent TKR or THR and received robot-assisted rehabilitation (RAR) as opposed to conventional rehabilitation (CR) in their review. In terms of discomfort and self-selected walking tempo, the study demonstrated that Hybrid Assistive Limb (HAL) training was much better than conventional rehabilitation. These results imply that the advantages of robotic assistance might go beyond the actual surgical process and into the phase of postoperative rehabilitation, which was not taken into account in this study. This would suggest that the benefits of using a robot for TKR may outweigh earlier estimates when taking into account both surgical performance and postoperative recovery.

Nonetheless, Nogalo et al[28] investigations into the constraints and difficulties of robotic systems in TKA provided general confirmation for the safety issues identified in this analysis. Among the issues they mentioned were excessive blood loss, iatrogenic soft tissue and bone damage, pinhole fractures, and infections connected to pins. This combination of findings supports the idea that, despite potential advantages, there are particular difficulties with robotic assistance for total knee arthroplasty. This combination of findings supports the idea that, despite potential advantages, there are particular difficulties with robotic assistance for total knee arthroplasty. Findings of longer operating periods and increased predicted blood loss in some RATKA operations are consistent with the mention of iatrogenic injuries being more common in the active robotic system and the stopping of the robotic TKA treatment.

In order to attain the intended limb alignment, Kayani et al[29] claim that RATKA reduces outliers and improves implant placing accuracy. This is in line with the conclusions of the present review, which shows that RATKA increased surgical precision in several investigations. Moreover, they found that robotic total knee arthroplasty (TKA) did not require a learning curve to achieve targeted implant location, an issue not explicitly explored in this review. In comparison to traditional TKA, Kayani et al[29] claim that RATKA is associated with less postoperative discomfort, enhanced early functional rehabilitation, and a shorter hospital stay. This offers a more positive evaluation of the postoperative outcomes of RATKA than this study, which produced inconsistent data on postoperative benefits. They did, however, concur with this review since there are no differences in the medium- to long-term functional outcomes. The limitations of robotic TKA, as highlighted by Kayani et al[29], are in line with the present findings. These constraints include high installation costs, additional radiation exposure, and compatibility issues.

Shatrov and Parker[30] conducted a review and synthesis of the literature comparing the PROMs of RATKR to conventional TKA. Their findings corroborate this review and demonstrate how computer-assisted surgical methods, like TKA and RTKA, improve the precision and uniformity of implant placement. Additionally, they saw a minor improvement in PROMs and implant survival compared to standard TKA. This is a more optimistic claim compared to this study, which found similar clinical outcomes for RATKA and traditional TKA. Shatrov and Parker[30] suggested that implant survival in people under 65 has an extra benefit, however, this research did not look at this specific population-based outcome.

To increase surgical precision, various RATKR techniques have been created; each has its own brand name. One solution that helps TKA is using a robotic arm through a haptic interface[31]. This semi-active system's job is to cut off the saw when the bone resection exceeds the upper bounds indicated in the surgical blueprint used before surgery. The technique enhances surgical precision in knee alignment by safeguarding soft tissue structures, such as the popliteal artery, posterior cruciate ligament, and medial collateral ligament[32,33]. It creates a three-dimensional model of the patient's knee using CT images, which enables precise prosthesis installation and sizing computations.

A different type of semi-active robotic technology uses a manually controllable robotic burr[34]. Although this technology was first made accessible for total knee arthroplasty (TKA), it has also been used in the past for partial knee arthroplasty, such as patellofemoral arthroplasty and unicompartmental knee replacement[33,35]. This technology tracks the burring tool's trajectory inside the navigational field instead of using a haptic interface. It stops the tibia or femur from being unintentionally resected by regulating the burr's exposure and velocity. This technique does not require prior CT scanning and is compatible with a wide range of prosthetic implant brands and kinds[36,37].

Securing the optimal implant fit and position is the driving force behind the development of new robotic technologies. These are self-contained, active systems that provide a three-dimensional image of the joint using CT scans[38]. The surgeon can predetermine the precise site, prosthetic size, and amount of bone resection. In line with standard surgical protocol, the technology verifies device placement using pins and navigation markers[39]. Next, the femoral and tibial incisions are made using the robotic instruments.

An additional development in RATKA technology is a motor-driven tool that facilitates precise tibial and femoral incisions by the surgeon[39-41]. A preoperative strategy is necessary to avoid problems when using a normal saw since this method uses an oscillating motion to accomplish exact alignment and placement of the prosthesis[41]. Unlike some of the previously described methods, this strategy does not utilize preoperative CT scanning[35]. One of the limitations of this technology is that it is only compatible with a specific type of knee prosthesis.

The study design had a number of intrinsic limitations that might have affected the final results. First off, a major drawback was the substantial heterogeneity, especially in the assessments of post-operative problems. This variability could have resulted from variations in the post-operative treatment, surgical technique, patient population, and study design across the several studies that were part of the analysis. The significant heterogeneity may limit the ability to draw firm conclusions by introducing bias and impairing the reliability of the subgroup analyses and pooled estimations. Secondly, data analysis at the individual patient level was not possible because the study relied on aggregated data. This made it more difficult to account for potential confounders and effect modifiers that might have affected the functional results and post-operative problems, such as patient comorbidities, surgeon experience, and rehabilitation regimens. Thirdly, Blum et al[15] stressed that the study failed to take into consideration the possible impact of patient expectations on the results. The results may have been skewed since patient expectations have a substantial impact on perceived satisfaction and functional scores. Furthermore, not all pertinent outcomes were fully assessed in the analysis. The study did not take cost-effectiveness into account, which is a crucial factor to compare manual TKA with RATKR because, as Mitchell et al[19] point out, the latter demands more resources.

There are a number of recommendations that may be made for future TKA research and practice that, if implemented, could improve the general standard of care for patients undergoing knee replacement surgery as well as the safety and outcomes of RATKR. First, since patient expectations were found to be a crucial factor in satisfaction following RATKR, practitioners are encouraged to incorporate pre-operative counseling to ensure appropriate expectations. Both post-operative satisfaction and perceived quality of life may increase as a result. Further investigation into this benefit is also recommended in light of the potential for increased surgical precision in RATKR. Further research should focus on understanding and optimizing the benefits of this increased precision, particularly with regard to improved alignment after surgery and potential benefits for gait. Further evidence that improved post-operative safety and efficiency is required comes from the longer surgery times and greater readmission rates associated with RATKR. In this instance, enhancing post-operative care, optimizing peri-operative care, and refining surgical techniques could be beneficial to lower these risks.

Conclusions

The investigation's findings provide significant insight into RATKR's security and efficacy. No appreciable differences in the pooled functional scores (HSS, KSS, WOMAC, and VAS) between RATKR and conventional methods was observed. There was no appreciable difference even in the subgroup analysis for hip and knee reconstructions, indicating that conventional techniques and RATKR were equally effective in improving functional results. However, this analysis of post-operative issues revealed a more nuanced picture. The RATKR group had much higher readmission rates despite the fact that there was no statistically significant difference in blood loss, which raises the possibility of safety concerns that require more investigation. Studies focusing specifically on postoperative complications revealed the complexity and range of outcomes in RATKR, as well as the high level of general variation. Numerous variables, including surgical technique, post-operative care, and patient characteristics, can affect these outcomes. For this reason, additional clinical trials are necessary to confirm the results of this and other studies with comparable objectives.

Informed Consent

Not applicable.

Ethics Approval

Not applicable.

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Conflict of Interest

There is no conflict of interest.

Authors' Contributions

Conceptualization, methods, data collection, data analysis, visualization, manuscript preparation and review by Abdullah H. Alshahrani.

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Availability of Data and Materials

The data will be available from the corresponding author and can be accessed by request via email.

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