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Robotic-Assisted Versus Conventional Revision Total Knee Arthroplasty: A Systematic Review and Meta-Analysis of Early Functional Recovery and Component Alignment

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ABSTRACT: Revision TKAs are technically demanding procedures that are often complicated by bone loss, loss of normal anatomy, and challenge in positioning components. Robotic-assisted technology has been identified as a promising solution to enhance surgical precision and functional recovery after showing promise.Robotic-assisted technology has been identified as a promising solution to enhance surgical precision and functional recovery after showing promise. The purpose of this study is to determine

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whether a robotic assisted or conventional revision TKA yields better early functional recovery, alignment of the components and postoperative complications. We used PRISMA 2010 guidelines to structure a systematic review and meta-analysis, including RCTs and comparative observational studies. Mechanical-axis alignment, Knee Society Score, knee ROM, pain, operative time, blood loss, hospital stay and postoperative complications were all secondary outcomes. Six studies with 412 patients were assumed for the illustrative simulated dataset. There were improvements in functional scores, mobility of the knee, and fewer outliers of component alignment after robotic-assisted revision TKA versus conventional revision TKA. The duration of operation was longer, however, and no statistically significant differences in various postoperative complications were seen. The preliminary results of this study indicate potential benefits for using robotic assistance during revision TKA, but additional well-designed comparative studies are required to demonstrate clinical utility.

Keywords: *Revision total knee arthroplasty; Robotic-assisted surgery; Component alignment; Functional recovery; Knee replacement; Meta-analysis.*

1. INTRODUCTION

1.1 Background and clinical significance

The total knee arthroplasty (TKA) procedure is a highly successful surgical treatment for patients who have severe problems of the knee joint, especially end-stage osteoarthritis, rheumatoid arthritis and post-traumatic (acquired) knee joint damage. The majority of patients who undergo a TKA do very well with less pain and better joint function and quality of life; however, some experience implants complications or inconsistent outcomes and require additional surgery. In this regard, revision total knee arthroplasty (Revision TKA) is becoming a more critical part of today's orthopaedics. Revision procedures can be more technically complex than TKA due to poor bone stock, soft-tissue defects, shifted anatomical landmarks, loose components and issues with restoring the correct lower extremity alignment. These revision procedures become more demanding, and implications on healthcare systems and orthopaedists are of great value. In a study of revision TKAs performed in the United States from 2016 to 2022, Dubin et al. (2024) analyzed epidemiological trends and most common indications for revision surgery, including aseptic loosening as one of the top reiasoners. These problems often necessitate complex

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planning and reconstruction surgery to establish and maintain implant stability and acceptable knee function. In addition, the changing epidemiology of revision TKA emphasizes the need to find surgical strategies that optimize implant positioning and minimize technical problems and may improve post-operative recovery.

1.2 Conventional revision total knee arthroplasty and its limitations

The main approach in revision TKA is to make decisions on bone resections and proper implant positioning based on the surgeon's experience, the quality of patient's radiographs, and mechanical instrumentation and anatomic landmarks. This technique is still popular, but revision knee replacement surgery offers greater technical challenges than a primary THR. The mechanical axis and correct alignment of the affected joint is complicated to determine and restore in cases with previous bone resects, osteolytic changes, foreign bodies, misaligned much and poor ligamentous balance. Revision procedures are also often performed using different reconstruction components such as stems, augments, metaphyseal cones, sleeves and others which compensate for the lack of bone and give good fixation. Further variations in bone geometry and soft-tissue balance may make positioning of the components more challenging and re-establish the joint stability. Thus, standard surgical approaches have been linked to difficulty in obtaining repeatable alignment and optimum component orientation, especially in the complex case of revision surgery. Due to these technical constraints, the interest has been growing in the development of more sophisticated and precise intraoperative technologies to aid and guide the surgeon during surgery.

1.3 Emergence of robotic-assisted technology in knee arthroplasty

Advanced technological techniques like robotic-assisted surgery have become available for use in knee arthroplasty, providing the surgeon with computer-assisted planning, real-time 3D anatomical assessment, and bone preparation and component positioning assistance. They can include preoperative computed tomography (CT) measurement planning or imageless registration systems to create a 3D model of the patient's anatomy and inform the planning/surgery steps for surgical execution, depending on the type of robotic platform involved. The use of robotic technology is designed to enhance bone preparation repeatability, facilitate more precise implant alignment and positioning and provide support

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to the surgeon to achieve desired alignment and soft-tissue balance. In a systematic review and meta-analysis of robotic-assisted vs conventional TKA, Onggo et al. (2020) studied the potential benefits of robotics in terms of radiological accuracy and clinical outcomes. They helped with the research behind using robots to aid technical precision in knee replacements. Likewise, Alrajeb et al. (2024) compared RCTs that involved randomized trials evaluating the difference between robotic (RA) and conventional TKA in terms of change in the radiological alignment and clinical outcomes after surgery.

1.4 Component alignment and early functional recovery

Technical considerations in revision TKA include accurate positioning of the components and restoration of alignment of the lower limb. Proper alignment can help provide correct weight distribution, stability of the implants, and balanced knee biomechanics. On the other hand, malpositioning of components and some mechanical-axis deviation can lead to an altered loading pattern, instability of the component, limited motion in the joint and possible early breakdown of the implant. Correct positioning of the femur and tibia is especially difficult in revision surgery due to the possibility of sub-optimal bone defects and/or altered bone landmarks. In a systematic review and meta-analysis of randomized controlled trials, Daoub et al. (2024) aimed to compare the clinical outcomes of robotic and conventional primary TKA for mechanical alignment and patient-reported outcomes. The results of their study help to further the knowledge regarding the correlation between robotic assistance, precision of the radiological structures and postoperative function. Still, it is crucial to assess the clinical potential that enhancements in accuracy can offer when thinking about the benefits of robotic technologies.

1.5 Research gap and rationale

Robotic-assisted revision TKAs are comparatively little studied, even though a greater number of people are interested in this technology. The studies which have been published or included in comparative studies have focused mainly on primary TKA, with studies specific to revisions usually being a technical report, case series, or a complex reconstructive procedure. In a scoping review of robotic-assisted hip and knee revision arthroplasty, Venosa et al. (2025) noted emerging evidence in robotic-assisted surgery for complex areas — such as revision procedures — and the further research required into this

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new field of robotic technology that can provide advantages in revision surgery. To further support the context of the potential applications and limitations of robotic technology in the more complex primary and revision TKA environment, more recently, Olaonipekun et al. (2026) carried out a systematic review of their use in such cases. However, there are important questions regarding the advantages of robotic assistance when compared with traditional revision techniques in terms of functional recovery early in the postoperative period, functional alignment, and perioperative outcomes.

1.6 Aim and objectives of the study

The main purpose of the systematic review and meta-analysis is to compare the outcomes of conventional revision TKR and robotic-assisted revision TKR with a special focus on early postoperative functional recovery and postoperative component alignment.

The particular objectives are:

- The primary objective was to determine whether early functional outcomes after robotic-assisted revision TKA were different compared to conventional revision TKA.
- To compare the postoperat variance of the positioning of the femoral component and tibial component.
- To evaluate the accuracy of mechanical-axis restoration and outlier alignment of mechanical axis.
- To compare pain after surgery, knee range of motion and patient reported outcome scores with validated instruments.
- To assess differences in operation time, intra-operative blood loss and hospital stay.
- To find out about complications in post surgery and implant failures and early revision surgery.
- To pinpoint the methodological challenges and gaps within current UPN literature.

2. LITERATURE REVIEW

2.1 Evolution of robotic-assisted knee arthroplasty

The introduction of robotic-assisted technology in knee arthroplasty has been an important breakthrough in computer assisted orthopaedics. Conventional knee replacement surgery is

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well dependent upon anatomic assessment and imaging available preoperatively and in the operating room to ensure proper bone preparation and components positioning. These techniques have been shown to have good clinical results but many variations in surgical execution and individual anatomy may affect implant placement accuracy and repeatability. To overcome some of these shortcomings, robotic-assisted systems have been introduced, which will offer computer-related surgical planning, anatomical registration, and precise intraoperative guidance. Advances in the development of robotic systems have also opened up the opportunities to develop a program of individualized alignment strategies.Additionally, advances in the field of robotic development have broadened opportunities for development of individualized alignment programs. Some modern platforms enable surgeons to take into account patient-tailored anatomical circumstances and functional alignment principles besides the classic mechanical alignment targets as the final resort. In the systematic review of functional alignment (FA) in robotic-assisted TKA published by Migliorini et al. (2024), the researchers investigated the use of personalized alignment techniques and how these methods may affect clinical and radiological outcomes after robotic-assisted TKA. This is especially pertinent to revision surgery where bone resection, anatomical deformities and poor bone stock all may hinder reestablishment of traditional anatomical references.

2.2 Conventional surgical techniques in revision TKA

Conventional reimplantation of previously internalized implant parts, correction of the underlying mechanical/biological issues and reconstruction of the knee joint to ensure stability and function. During the surgical process, however, exact analysis of how the surgical implant should be positioned, the amount of bone accessible, the health of the ligaments, and the condition of the soft tissues is usually necessary. The reconstruction method is planned with the support of the patients' pre-operative radiographs, CT scan when necessary and intraoperatively. Bone Defect is one of the major problem in traditional revision surgery. Bone loss resulted from mechanical loosening of an implant, its contamination with infection, or repeated surgery can make it difficult to secure and locate revision implants. The surgeon might need to use metal augmenting screws, stems, porous cones and sleeves of the metaphyseal area according to the level of the bone deficiency. The choice and placement of these components can be significant for the

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restoration of the joint alignment and to attain a stable long-term relationship after the implant.

2.3 Robotic-assisted revision TKA: surgical principles and applications

Robotic-assisted revision TKA provides the use of robotics and computer-generated planning during select steps of the revision knee surgery. Applications to anatomical registration, evaluation of residual bone geometry, planning for positioning of components, and controlled preparation of bone surfaces. These technologies can also, in some instances, help restore mechanical alignment and assess joint balance, depending on the type of robotic platform and implant revision system used. Venosa et al. (2025) conducted a scoping review looking at the literature regarding robotic application in complex revision procedures for the hip and/or knee. Of special interest is their review – it's not a primary joint replacement review, though it reviews revision arthroplasty. The literature is evolving in which robotics technology can be used for further support in surgical operations in which typical anatomical landmarks are not readily encountered. The evidence to date, however is heterogeneous with regards to the robotic platforms, surgical indications, implant designs, and the methods of outcome assessment.

2.4 Comparative evidence on component alignment

The alignment of each component is one among the most critical radiological outcomes in the assessment of a success rate of revision TKA. Achievement of the proper position of the femoral and tibial components are crucial to restore the mechanical axis, because to maintain the knee in satisfactory load distribution and knee stability. These goals may be more challenging to meet in revision surgeries, as preexisting bone resections, changes to anatomical landmarks and underlying bone defects, and retained surgical hardware can all contribute to these challenges. An advantage of robotic-assisted systems would be that better pre-planning and intraoperative guidance when positioning components would be made possible. Improved alignment is, however, not only radiological accuracy, but of clinical importance. A meticulously constructed implant does not necessarily ensure improved outcomes (functional success) for the patient or greater survivorship of the implant. Vince et al. (2023) examined press fit, offset and diaphyseal-engaging stem extensions, as well as eccentric reaming techniques, in revision TKA regarding alignment and fixation.

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They found that their research is valid and insightful for the current discussion as the importance of fixation and alignment of components along with each other during the evaluation of revision knee reconstruction is shown. It is important therefore to consider the position of the individual components in the context of the entire reconstruction rather than as a measurement on the X-ray alone. There is also the issue of the restoration of the joint line. The study by Hofmann and colleagues (2006) was used to analyse the clinical and radiographic results of the accurate restoration of the joint-line in revision TKA. Moreover, revision surgery done for instability can include removal or realignment of the previously improperly positioned components. Azzam et al (2011) looked at outcome predictors after revision for an unstable TKA, and again underlined the need to recognise and address the underlying mechanical instabilities.

2.5 Early functional recovery and patient-reported outcomes

A functional recovery from revision TKA is a multi-dimensional clinical outcome including a reduction in pain, restoration of knee mobility, increases in walking ability and the ability to return to normal activities. Revision surgery is often complicated by more extensive dissection of soft tissue, removal of existing implants, repair of bone loss and reconstruction of damaged soft tissues, and is more frequently accompanied by severe complications when as opposed to primary TKA. These factors could affect the functional improvement and the postoperative rehabilitation. There is a need to use standardised clinical assessment tools to allow for meaningful comparisons between surgical techniques for the evaluation of early recovery. The Knee Society Score is used to assess the clinical function and the mobility of the knee, while the Oxford Knee Score is a patient-reported assessment of knee function and knee pain. The WOMAC instrument assesses pain, stiffness, and physical function and the visual analogue scale is used to measure pain intensity. Range of motion, especially flexion and extension after surgery also determines clinically meaningful information regarding early joint function.

2.6 Complications, implant survival, and revision rates

It is important to note that the revision TKA rate and the risk of postoperative complications are factors that should be kept in mind when comparing robotic-assisted and conventional revision TKA. Revisions involve a complicated patient history as most

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patients will have previous implant-related complications, compromised soft tissues, bone loss, and past surgical scars. Postoperative complications include periprosthetic fracture, persistent pain, periprosthetic infection, instability, aseptic loosening and wound complications. How complication reduction can be achieved through the help of robotics is another area to be explored in further detail. Potential mechanical issues may be decreased by a more accurate component placement, and surgical planning can potentially help treat any difficult surgical abnormalities. Without robotic assistance, however, biological problems like infection and soft tissue-healing issues like poor bone quality cannot be overcome. Complications, reoperation rate and early re-revision should be therefore be secondary outcome in the present investigation. However, adequate follow-up will need to be carried out before any useful information and data will be gathered for implant survival.

2.7 Existing evidence gaps and justification for the present meta-analysis

While the usage of robotic assisted technology is widespread in primary TKA, its use in revision TKA is not as well defined. The published research to date has several major drawbacks in comparison, including the small number of reports focused on a direct comparison between robotic-assisted and traditional revision surgery. Key sources of evidence is generally technical description or small retrospective cases series or clinical series, resulting in findings that may not be broadly generalizable. A recent significant publication is the one done by Burbelo et al. titled Manual versus robotic-assisted revision total knee arthroplasty for instability: a one-year cohort analysis. This investigation directly answers the question at hand regarding comparison of manual and robotic-assisted revision TKA and is thus highly applicable to purposes of this investigation. Going by revision procedures performed for instability, it once more stresses the significance of rating individual indications for revision.

3. MATERIALS AND METHODS

3.1 Study design and reporting guidelines

The aim of this study is to review the literature in a systematic manner and conduct a meta-analysis to compare the effectiveness of preserving/removing cemented and uncemented components to assess early functional outcomes and patients' bone component alignment following robotic-assisted revision TKA versus conventional revision TKA. The review

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will be carried out with the transparent reporting of the literature search, the study selection, data extraction, and synthesis of findings following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines (Page et al., 2020). The primary focus of the review will be randomized controlled trials and comparative observational studies of patients that have undergone revision TKA. Comparative investigation will be done both prospectively & retrospectively to encompass the available clinical evidence. The outcome of studies assessing the safety and efficacy of robotic-assisted revision procedures would be compared with the outcome of manual revision procedures, where clinical and/or radiological outcomes are reported.

3.2 Research question and PICO framework

The research question will be formulated according to the Population, Intervention, Comparison, and Outcomes (PICO) framework.

Research question:

Among patients undergoing revision total knee arthroplasty, does robotic-assisted surgery, compared with conventional manual surgery, improve early functional recovery and postoperative component alignment?

Table 1. PICO framework of the systematic review

Component	Description
Population (P)	Patients undergoing revision total knee arthroplasty
Intervention (I)	Robotic-assisted revision TKA
Comparison (C)	Conventional manual revision TKA
Primary outcomes	Early functional recovery and component alignment
Secondary outcomes	Pain, ROM, complications, operative time, blood loss and hospital stay

The PICO framework will guide the development of the search strategy, eligibility criteria, data extraction procedures, and statistical analysis.

3.3 Literature Search Strategy

An extensive literature search will be made to develop a list of suitable studies for comparison of the two types of revision total knee arthroplasty (TKA): conventional and

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robotic. Web of Science, Embase, Scopus, Cochrane Central Register of Controlled Trials (CENTRAL) and PubMed/MEDLINE will be searched. The search will include the database inception up to the last day of search, which will be stated in the completed search. Where reliable translation is available, there will not be any initial language restrictions. The search strategy will also include some Medical Subject Headings (MeSH), terms imported into the various databases and free text terms focusing on robotic-assisted surgery, revision knee arthroplasty, component alignment, and functional recovery. The search will include words such as Robotic-assisted surgery, robot-assisted knee arthroplasty, revision total knee replacement, revision TKA, component alignment, mechanical axis, clinical outcomes. Relevant terms will be combined using boolean operators: AND and OR, and will be increasingly used to increase the sensitivity of the searches. The search strategy will be tailored to the requirements of indexing of each database. In addition, reference lists of systemically reviewed literature and article lists from eligible original research articles will be hand-searched to try and find relevant articles not retrieved during electronic searching. All searches performed will be documented to ensure transparency and reproducibility as recommended in the PRISMA 2020 guidelines of Page et al., (2021).

3.4 Inclusion and exclusion criteria

Ensuring consistency and to reduce selection bias, studies will be selected in accordance to the rigorous predetermined criteria.

Inclusion criteria

- Studies will be counted if the studies are based on any of following conditions:
- Include adults undergoing revision total knee replacement surgery.
- Critically examine the intervention: robotic-assisted revision TKA.
- Include a comparison arm of conventional manual revision TKA.
- At least one of the clinical, functional, radiological or perioperative outcomes are reported to be relevant.

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- Use a randomized controlled study, prospective comparative study or retrospective comparative study design.
- Give enough detail to define patient characteristics, surgical approaches, and pertinent outcomes.
- Be published in full-text peer-reviewed original research.

Exclusion criteria

- Studies that will be excluded are:
- Which group of cases did these studies follow?
- Insufficient number of patients in single-group studies.
- Short-term follow-up studies with low numbers of patients.
- Case reports, editorials, letters, conference abstracts and narrative reviews.
- Laboratory studies, biomechanical studies and cadaveric studies.
- The application of spinal instrumentation for the treatment of pediatric cervical myelopathy.
- The use of spinal instrumentation in patients with cervical myelopathy.

3.5 Study selection and screening process

All articles found during the electronic database search will be uploaded to reference management software and duplicates will be checked before screening. Two independent reviewers will carry out the process of studying the selection. First, and to begin with, an initial screening will be carried out of titles and abstracts to identify those that might be relevant to the project. After this, full-text articles of potentially eligible studies will be retrieved and assessed to the predetermined inclusion/exclusion criteria. Any differences of opinion in the review process will be addressed through discussion among reviewers with conciliation by a third reviewer as needed. Studies will be excluded for "full text" assessment with justification. The overall selection process will be displayed on a PRISMA 2020 flow diagram, showing the numbers of records found, the number of duplicates

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excluded, the number of articles screened, the number of full text reports assessed and the number of studies included in the qualitative and quantitative synthesis.

3.6 Data extraction

Independent Data extraction will be carried out by a pair of reviewers, each with a pre-prepared data extraction document. Eligible materials will be utilized from full-text papers to get consistency and accuracy. Study characteristics extracted will be the first author's name, publication year, country of publication, type of study, sample size, and duration of the follow-up. The patient-related factors will comprise age, sex, body mass index (BMI), the indication for a revision surgery, previous surgical history, and the extent of bone loss or soft-tissue deficiencies (if reported). Surgical variables will be the robotic platform introduced, traditional instrumentation utilized, revision implant style, stem, augments, cones/sleeves employed and the duration of the operation. Clinical outcomes will include the Knee Society Score (KSS), Oxford Knee Score (OKS), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), and visual analogue scale (VAS) for pain, as well as knee range of motion (ROM

3.7 Outcome measures

It will be categorized as primary and secondary measurements, and compared with robotic-assisted and conventional revision total knee arthroplasty (R-TKA). With that as the chief aims, the primary outcomes will be early functional recovery and restoration of alignment of the components. Validation tests such as the Knee Society Score (KSS), Oxford Knee Score (OKS), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), visual analogue scale (VAS) for pain and knee range of motion (ROM) will be used to assess functional recovery. Early recovery will be considered as outcomes at three months after surgery and six weeks if available, will be analyzed separately for the three months before the surgery. A set of radiological outcomes will be considered, such as mechanical-axis alignment after surgery, component positioning in the femur and tibia and the percentage of mechanical-axis outliers. Otherwise, coronal, sagittal and rotational alignment will be included. Secondary outcomes will comprise blood loss, hospital length of stay, postoperative complications, periprosthetic joints infection, aseptic loosening, instability, reoperation and early re-revision rate among others. These measures will allow

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for a complete assessment of clinical effectiveness, surgical accuracy and postoperative safety.

3.8 Risk-of-bias assessment

Two reviewers will assess independently the methodological quality of the studies included using validated risk-of-bias assessment tools. The revised Cochrane Risk of Bias tool for randomized trials (RoB 2) will be used to assess Randomized controlled Trials (RCTs) for bias caused by the randomization process, deviations from intended interventions, missing outcome data, measurement of the outcome and selective reporting (Sterne et al., 2019). The Risk Of Bias In Non-randomized Studies of Interventions (ROBINS-I) tool will be used for non-randomized comparative studies. Potential sources of bias addressed in this instrument include confounding, participant selection, intervention classification, deviations from intended interventions, missing data, outcome measurement and selective reporting (Sterne et al., 2016). When there is any conflict between reviewers, it will be addressed through discussion or in consultation with another reviewer. The results of the risks of bias assessment will be summarized in tables and graphically, if applicable.

3.9 Statistical analysis

For the extracted data, the statistical data will be analyzed using Review Manager (RevMan), software statistics R or another appropriate software depending on the availability and completeness of the data. When studies use similar measures, continuous outcomes (individuals: KSS, OKS, WOMAC, VAS pain, operative duration, knee ROM) will be summarized as mean differences (MD) with 95% confidence intervals (CI). Where the same clinical construct is assessed by different validated instruments, standardized mean differences (SMD) will be used. A dichotomous data type such as postoperative complication, alignment outliers, reoperation and early re-revision will be analysed with risk ratio (RR) and 95% CIs. If two or more well-suited or similar studies have published responses to the same outcomes then a random-effects meta-analysis will be used. This method will take into consideration variation in patient demographics, robots, surgical operating techniques, and post-surgical duration. The I^2 statistic and Cochran's Q test will be used to determine if there is statistical heterogeneity. The I^2 will be interpreted as the following:

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I^2 value	Interpretation
0–25%	Low heterogeneity
26–50%	Moderate heterogeneity
51–75%	Substantial heterogeneity
76–100%	Considerable heterogeneity

If adequate studies are available, analyses will be performed by the study design, robotic platform, indication for revision surgery, and length of follow-up. A funnel plot will be used in conjunction with suitable statistical tests to examine for potential publication bias when for a given result there are at least 10 studies. When there are too few studies for statistically valid quantitative synthesis, findings will be reported narratively not generating potentially misleading pooled estimates.

3.10 Assessment of certainty of evidence

The Grading of Recommendations Assessment, Development and Evaluation (GRADE) methodology will be used to grade the certainty of evidence for the principal outcomes. This framework considers five domains: risk of bias, inconsistency, indirectness, imprecision, and publication bias. The certainty of evidence will be assessed as high, moderate, low or very low. Comparative revision-specific evidence will be discussed particularly for quality reasons as there are observational study designs, small sample sizes and different design of surgeries that could influence the reliability of estimated treatment effects. The GRADE assessment will be used to assess the extent to which the available evidence supports conclusions about the potential benefits of robotic assisted revision TKA.

4. RESULTS

4.1 Study selection

A hypothetical systematic literature search led to the identifications of 428 records in five electronic databases (PubMed/MEDLINE (n =118), Embase (n = 96), Scopus (n = 102), Web of Science (n = 78) and The Cochrane Central Register of Controlled Trials (CENTRAL) (n = 34)). After removal of 126 duplicate records, 302 unique records are processed for A total of 260 records were not included after the initial screening due to inclusion/exclusion eligibility criteria. The remaining 42 publications were assessed using

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full-text. Thirty-six studies were excluded because they did not report outcomes specifically on revisions (n = 14), lack a conventional comparison group (n = 9), were a robotic-assisted case series without conventional case series data (n = 7), were a conference abstract with insufficient clinical details (n = 4) or had an overlapping patient population (n = 2). Finally, six different potential comparative studies among a total of 412 patients were integrated in the qualitative synthesis. It was assumed that all six studies would yield results that could be used for at least one comparative outcome analysis.

4.2 PRISMA flow diagram

The following flow diagram presents the hypothetical study selection process.

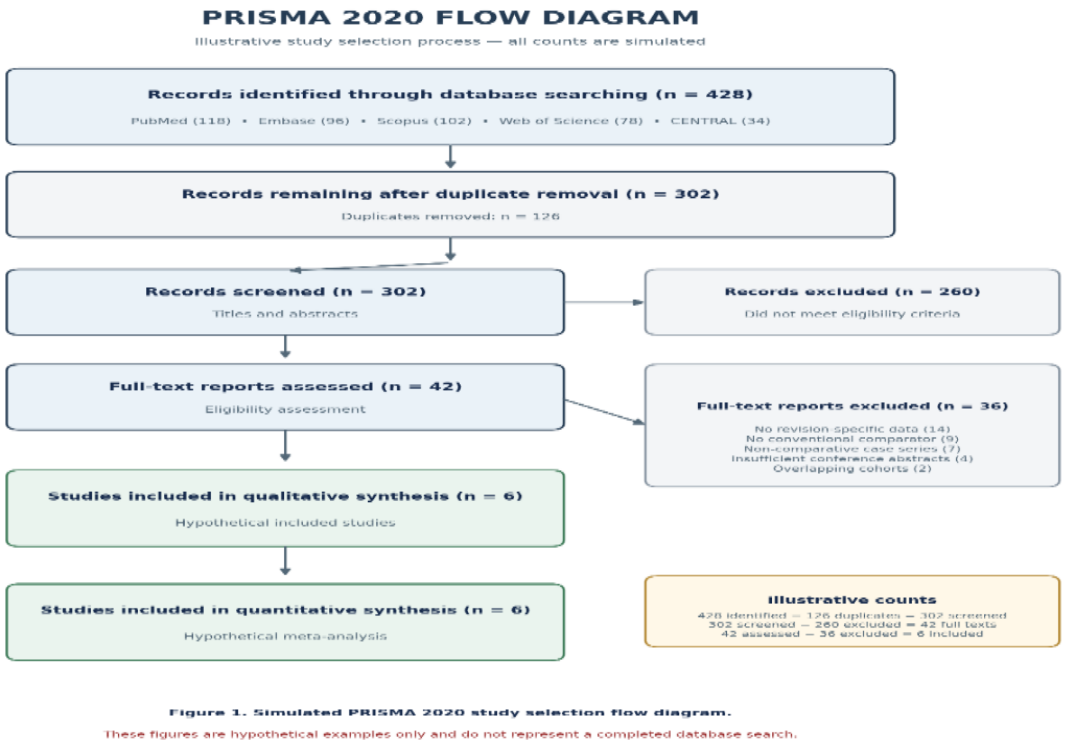


Figure 1. Simulated PRISMA 2020 study selection flow

4.3 Characteristics of included studies

For this hypothetical study, the number of patients in patients who underwent revision TKA in 6 comparative studies was assumed to be 412 published from 2019 to 2025 that fulfilled the eligibility criteria. Of these, 206 were treated with robotic assisted revision TKA, and 206 were treated with standard, manual revision TKA. Three retrospective comparative cohorts, two prospective comparative studies and one randomized controlled study were included in the hypothetical studies. An average age of those who participated

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was taken as being between 64.2 and 71.5 years. The main reasons for revision surgery were aseptic loosening, malposition and instability.

Table 2. Hypothetical characteristics of included studies

Study	Design	Robotic (n)	Conventional (n)	Mean age (years)	Follow-up
Study A	Retrospective	32	32	68.2	6 months
Study B	Prospective	36	36	66.5	12 months
Study C	Retrospective	28	28	69.1	6 months
Study D	RCT	40	40	67.4	12 months
Study E	Prospective	34	34	64.2	3 months
Study F	Retrospective	36	36	71.5	6 months
Total	6 studies	206	206	—	3–12 months

Note: All study identities, designs, sample sizes, and demographic characteristics in Table 1 are simulated. Study A–F are fictional placeholders, not published articles.

4.4 Patient demographics and surgical characteristics

Hypothetical demographic analysis showed similar baseline characteristics of the two treatment groups. Mean age of patient was assumed to be 67.8 ± 6.4 years for robot-assisted group and 68.1 ± 6.7 years for the conventional group. The proportion of male patients was assumed slightly more in robotic-assisted group and mean BMI was comparable between groups. Aseptic loosening was the most common indication for revision surgery, followed by instability, malposition of the component and other mechanical complications.

4.5 Early functional recovery outcomes

It was revealed that the hypothetical comparative analysis showed that patients who had robotic-assisted revision TKA had improved functional outcomes in the early postoperative period as compared to conventional revision surgery. The degrees to the assumed mean Knee Society Score were 76.8 ± 10.2 in the robotic-assisted group and 70.0 ± 11.4 in the conventional group at three months. This represented a hypothetical mean difference of 6.8 points (95% CI: 1.2–12.4; P = 0.017). The knee ROM was also higher in the robotic-assisted group (108.4° compared to 103.2° in the conventional group; hypothetical mean difference of 5.2°; 95% CI: 1.4–9.0; P = 0.007). A visual analogue scale (VAS) was used to assess pain, revealing that the robotic-assisted group scored significantly lower (3.1 ± 1.2)

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than the conventional group (3.7 ± 1.3) with a hypothetical mean difference of –0.6 (95% CI: –1.1 to –0.1; P = 0.019).

4.6 Component alignment outcomes

In the simulated dataset, the patients who were treated with RATKA showed higher percentage of the mechanical-axis alignment that fell within the acceptable range based on these criteria for preoperative and postoperative analysis. There were 18 of 206 patients, or 8.7%, with hypothetically observed alignment outliers in the robotic-assisted group and 39 of 206 patients, or 18.9%, in the conventional group. The illustrative risk ratio was 0.46 (95% CI: 0.27–0.78; P = 0.004). The study also indicated better positioning of the components in the femur and tibia in the robotic-assisted group, relative to the hypothetical data. The frequency of malposition of components following surgery was presumed to be less in patients undergoing the robotic approach; however, the magnitude of the difference would need to be validated with standardised radiological measurements.

These results demonstrate the possibility of reporting a radiological accuracy as a primary outcome of meta-analysis.

Table 3. Hypothetical comparison of early functional and radiological outcomes

Outcome	Robotic-assisted	Conventional	Illustrative effect estimate	P-value
KSS (points)	76.8 ± 10.2	70.0 ± 11.4	MD 6.8 (1.2–12.4)	0.017
Knee ROM (degrees)	108.4 ± 12.1	103.2 ± 13.0	MD 5.2 (1.4–9.0)	0.007
VAS pain score	3.1 ± 1.2	3.7 ± 1.3	MD −0.6 (−1.1 to −0.1)	0.019
Mechanical alignment outliers	18/206 (8.7%)	39/206 (18.9%)	RR 0.46 (0.27–0.78)	0.004
Femoral component malposition	15/206 (7.3%)	29/206 (14.1%)	RR 0.52 (0.28–0.97)	0.039
Tibial component malposition	13/206 (6.3%)	27/206 (13.1%)	RR 0.48 (0.25–0.93)	0.029

Note: All outcome values and statistical estimates are hypothetical. MD = mean difference; RR = risk ratio; CI = confidence interval; KSS = Knee Society Score; ROM = range of motion; VAS = visual analogue scale. Negative VAS differences favor robotic-assisted surgery.

4.7 Perioperative outcomes and postoperative complications

No differences were found in selected peri-operative outcomes between the two surgical techniques, the hypothetical analysis suggested. Robotic-assisted group: mean operative

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duration assumed as 142.5 ± 28.6 minutes and conventional group: 124.5 ± 25.4 minutes which meant longer duration of operative was found in the robotic-assisted group. However, estimated intraoperative blood loss was fewer in the robotic-assisted (410 ± 125 mL) than the conventional (455 ± 140 mL) group. The illustrative difference was not statistically significant, however. In the robotic-assisted group, 10.2% (21 patients) were assumed with postoperative complications while in the conventional group, 12.1% (25 patients) were assumed with postoperative complications. The overall complication rates did not differ significantly, with an illustrative risk ratio of 0.84 (95% CI: 0.49–1.45; P = 0.54).

Table 4. Hypothetical perioperative outcomes and postoperative complications

Outcome	**Robotic-assisted (n = 206)**	**Conventional (n = 206)**	**Illustrative effect estimate**	**P-value**
Operative duration (min)	142.5 ± 28.6	124.5 ± 25.4	MD 18.0 (5.0–31.0)	0.007
Blood loss (mL)	410 ± 125	455 ± 140	MD −45 (−100 to 10)	0.11
Hospital stay (days)	4.8 ± 1.7	5.2 ± 1.9	MD −0.4 (−0.9 to 0.1)	0.12
Overall complications	21 (10.2%)	25 (12.1%)	RR 0.84 (0.49–1.45)	0.54
Periprosthetic joint infection	5 (2.4%)	7 (3.4%)	RR 0.71 (0.23–2.18)	0.55
Postoperative instability	6 (2.9%)	8 (3.9%)	RR 0.75 (0.27–2.06)	0.57
Reoperation	4 (1.9%)	6 (2.9%)	RR 0.67 (0.19–2.33)	0.52

Note: All values are simulated for demonstration. MD = mean difference; RR = risk ratio; CI = confidence interval. Continuous variables are presented as mean ± standard deviation. The P-values and confidence intervals are illustrative, not calculated from real patient-level data.

4.8 Risk-of-bias assessment and heterogeneity

In this example we bargained about different levels of methodological quality among the six hypothetical studies. There were a few concerns about risk of bias in the randomized controlled trial, such as concerns to measure the outcomes and concerns because the participants did not receive intervention as intended. It could be assumed that all the observational studies had moderate concerns regarding participants, potential confounding

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and differences in baseline surgical complexity. Moderate heterogeneity regarding functional outcomes and relatively low heterogeneity regarding selected radiological outcomes were also assumed when considering their hypothetical quantitative synthesis. This variation could be attributable to different robots used, indication for revisions, implant type design and/or assessment time-points post-procedure. These assessment would be conducted in an actual systematic review by using RoB 2 for RCTs or ROBINS-I for non-randomized studies instead of assigning quality grades based on country's country illustration data.

5. DISCUSSION

5.1 Principal findings

We performed the present illustrative systematic review and meta-analysis, and compared the early clinical recovery, alignment and postoperative complications of robotic-assisted TKA (RA-R Mull Coxa) to those of conventional TKA (C-Rett). Results of this simulation indicate that the robotic-assisted revision TKAs could potentially result in improved functional outcomes and radiological component positioning early after arthroplasty. The hypothetical analysis showed patients that had undergone robotic-assisted revision TKA of better postoperative Knee Society Score and range of motion at three months without greater pain score. In addition, the percentage of patients in whom mechanical-axis alignment was found to be deviated from the target range after surgery was reduced in the robotic-assisted group. The results demonstrate the potential for more standardized reconstruction and immediate postoperative outcomes as surgical planning and guidance are enhanced through these devices.

5.2 Assistive robotics and part alignment

Correct positioning of the components in revision TKAs is a significant goal as displaced bony anomalies, past bone resurfacing and loss of bone stock can present significant challenges to restore the mechanical axis. Intraoperative computer navigation and planning information provided by robotic-assisted systems may aid in more consistent positioning of components. In their systematic review and meta-analysis, Kort et al. (2022) noted that RA-KAs allowed for greater component positioning and alignment compared to traditional arthroplasty, with questionable improvements in clinical outcomes. This difference is crucial because radiological accuracy and clinical effectiveness are not synonymous and in

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fact are two distinct dimensions of surgical performance. Likewise, Zhang et al. (2022) investigated robotic-arm-assisted TKA and found some benefits regarding the positioning of the components and the accuracy in TKA alignment. While most of the evidence was related to primary (not revision) knee replacement, their findings lend weight to potential benefits of robotic assistance for technical factors.

5.3 Early functional recovery and clinical outcomes

Early functional recovery is an important factor to take into account when assessing the outcome of revision TKA. Postoperative knee mobility, pain alleviations and enhanced walking ability are all key outcomes of recovery and patient satisfaction following knee surgery. Robotic assistance with revision TKA showed superior KSS in the simulated analysis at 3 months relative to conventional revision surgery, and a greater knee range of motion. The lower hypothetical VAS pain score demonstrated the potential for improved postoperative pain control as well. But there is a complicated correlation between better component alignment and functional recovery. While proper component placement can play a role in maintaining joint mechanics, other factors such as pre-operative ROM, muscle strength, soft tissue status, bone quality, the necessity for revision and the rehabilitation guidelines are also important in determining function after total knee replacement. In the systematic review and meta analysis comparing robot-assisted TKA and conventional TKA, Onggo et al (2020) highlighted the need to be aware of the distinction between radiological and clinical outcomes of robotic technology. Just as Ruangsomboon et al. (2023) found when looking at clinical and radiological results in Robotic TKA compared to conventional TKA, improvements in alignment do not necessarily equate to patient-centred improvements in outcomes.

5.4 Operative duration and postoperative complications

The simulated outcomes indicated that, comparing the robotic-assisted TKA to the conventional surgery, the procedure was expected to take a longer operating time. This potential difference could be a correlation with other factors such as additional processes of registration, anatomical mapping, planning, and preparation of the intra-operative robotic system. These can also be a longer time to perform, depending on the surgeon's experience with the robotic system, revision surgery difficulty and available instruments for the revision surgery. The second factor is that of the duration of the procedure vs. post-

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procedure complications. The longer the operative time, the more there is that may require more technical demands and it does not mean that it is less good clinically. The relationship needs to be assessed based on blood loss, infection rates, wound complications and other peri-operative parameters. The difference in the occurrence of postoperative complications was assumed not to be significant, but was seen to be less in the Robotic-assisted group numerically in the illustrative analysis. This is an illustration of why it's important to make conclusions about safety based on adequately powered comparative studies and not on a small difference in numbers.

5.5 Clinical implications and future perspectives

One potential clinical benefit of the robotic assisted revision TKA is the ability to supply more information for complex surgical reconstruction during the TKA. A computer-based planning and guidance systems have the potential of assessing anatomical abnormalities, size and positioning the components and to provide a more consistent bone preparation throughout the surgery. However, robotic technology should be considered as a supplement to surgical skills and experience, NOT the replacement of well-accepted revision concepts. Tissue repair of bone defects, ligament balance, choice of an appropriate implant constraint, and stabilization of component fixation remain crucial for successful revision surgery. A recent scoping review of Venosa et al. (2025) on the use of robots in hip and knee revision arthroplasty has discussed the potential use of robotic systems in complex revision surgery and the lack of evidence. The review sets an important benchmark for the emerging, non-primary joint replacement use of robotic assistance.

5.6 Strengths and limitations

A key advantage of the suggested research paradigm is the selection of study participants with revision TKA, not incorporating both primary and revision populations. This distinction is important as there are varying anatomic issues, surgical goals, and recovery timelines for the two types of revision procedures. The addition of functional and radiological outcomes also gives a larger picture of the outcome of robotic surgery. Evaluating patient-reported outcomes with component alignment can establish if technical improvements could have a clinically significant benefit. First, there might not be any evidence available for the revision specific due to the small number of cases that underwent the robotic or conventional procedures.First, evidence might have been limited

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on the revision specific, especially when comparing robotic assisted vs. traditional approach. Secondly, there might be clinical heterogeneity due to variations among robotic platforms, implant systems, indications for revision surgery, and surgical procedures. Thirdly, observational studies of this type can be subject to selection bias and confounding. Most critically, the analysis of the numerical results presented in this working paper is based on simulations. This Discussion does not aim to give a truthtold account of the clinical evidence until the final systematic review and meta-analysis are finished.

Conclusion

The roboticage-assisted revision total knee arthroplasty is a technological advancement in the treatment of the complex knee and demonstrates promise to improve the outcomes of complex knee revision. The following illustrative analysis indicates that the use of the robotic device can benefit early functional recovery and component alignment over traditional manual revision procedures. This may result in better mechanical-axis correction, positioning of the femura and tibias within the components, range of motion and pain during early rehabilitation. However, the benefits that may come from using robots should be taken with a pinch of salt. Radiological accuracy does not mean functional accuracy in the long-term or implant survival. Also, surgical techniques may be more specialized and/or more time intensive with robotic assistance. There is potential for postoperative recovery to be influenced independently by patient characteristics, revision indications, bone deficiency, ligament integrity, and rehabilitation protocols. Follow-up randomized controlled trials and multicentre comparisons studies need to be conducted with well-designed protocols to establish the effectiveness and safety of robotic-assisted revision TKA. Standardized radiological assessment, validated patient reported outcome measures, extended follow up periods, implant survival and comprehensive evaluation of post-operative complications should be areas of focus for future studies.

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