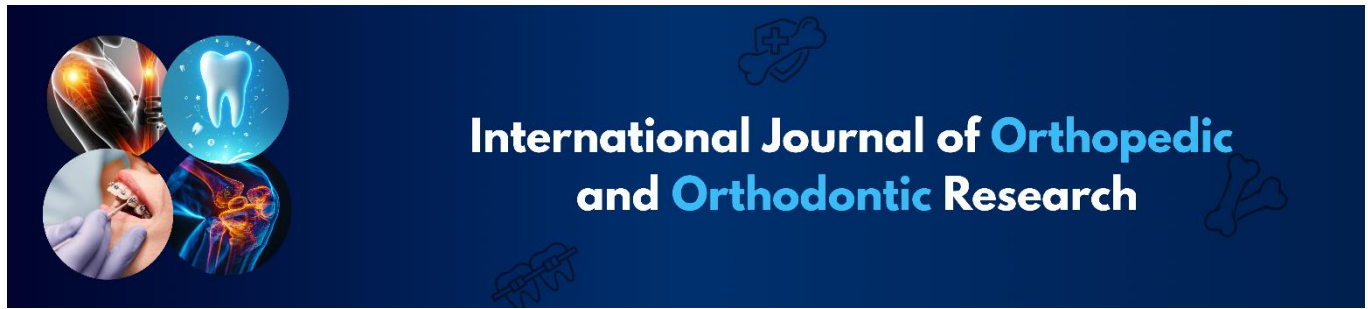




Robotic Surgery in Total Knee and Hip Arthroplasty: Current Clinical Evidence

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Abstract

Introduction: the incorporation of robotic surgery into total knee and hip arthroplasty has expanded the capacity for three-dimensional planning, alignment control, and component positioning. However, it remains controversial whether technical superiority translates into clinically relevant benefits.

Objective: to critically analyze recent evidence on robotic surgery in total knee and hip arthroplasty, comparing surgical accuracy, clinical and functional outcomes, safety, complications, revisions, and perioperative aspects.

Methods: a descriptive and analytical systematic review conducted according to PRISMA 2020, with searches of bibliographic databases for studies published between 2021 and 2026. Clinical trials, comparative studies, systematic reviews, and meta-analyses involving primary robotic arthroplasty were considered.

Results: the studies demonstrated a consistent advantage of robotics in alignment accuracy, reduction of outliers, acetabular positioning, restoration of limb length, and reproducibility of planning. In knee arthroplasty, functional gains were modest and heterogeneous; in hip arthroplasty, radiographic improvement was not accompanied by uniform superiority in clinical scores. Complication rates were similar to or lower than those of conventional techniques, although operative time was longer.

Conclusion: robotic surgery is becoming established as a highly accurate tool with potential for arthroplasty personalization, but long-term clinical superiority and cost-effectiveness still require confirmation through multicenter studies with extended follow-up.

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Keywords: Robotic surgery, Total knee arthroplasty, Total hip arthroplasty, Alignment, Component positioning, Clinical outcomes

1. Introduction

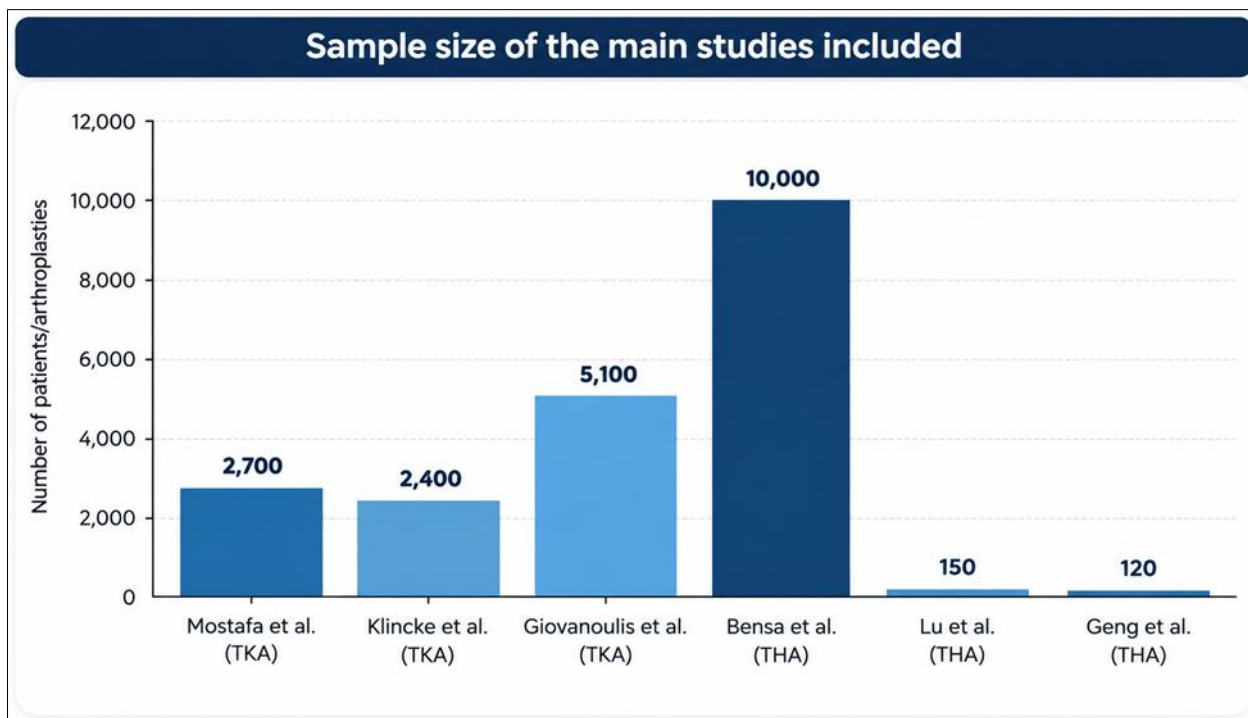
Knee and hip osteoarthritis are major causes of chronic pain, functional limitation, and loss of independence, especially in older adults. When the disease reaches advanced stages and no longer responds adequately to conservative measures, total arthroplasty becomes one of the main strategies for pain relief and functional recovery. Although conventional techniques have well-established outcomes, the quality of reconstruction depends on factors such as alignment, component position and orientation,

soft-tissue balance, and restoration of joint biomechanics, all of which may influence stability, wear, satisfaction, and the need for revision (BENSA *et al.*, 2025; MOSTAFA *et al.*, 2025) ^[1, 8].

The incorporation of robotic platforms represents one of the most important technological changes in contemporary arthroplasty. These systems combine digital planning, anatomical registration, and assisted execution to reduce deviations from the surgical plan and enable personalized adjustments. In total knee arthroplasty (TKA), robotics has been associated with greater accuracy of bone cuts, fewer mechanical-axis outliers, and better joint-line control; in total hip arthroplasty (THA), it stands out for three-dimensional

acetabular planning, control of inclination and anteversion, and restoration of limb length and offset (KLINCKE *et al.*, 2026; GENG *et al.*, 2025) ^[6, 3].

The quantitative robustness of recent evidence can be observed in the sample sizes of the main studies included in this review. As shown in Graph 1, the meta-analyses by Bensa *et al.* (2025) ^[1] and Giovanoulis *et al.* (2026) ^[4] included the largest populations, whereas multicenter clinical trials such as those by Lu *et al.* (2024) and Geng *et al.* (2025) ^[3] provided direct experimental evidence on accuracy and perioperative outcomes. This combination of large quantitative syntheses and randomized trials strengthens the critical assessment of the technology's effectiveness.



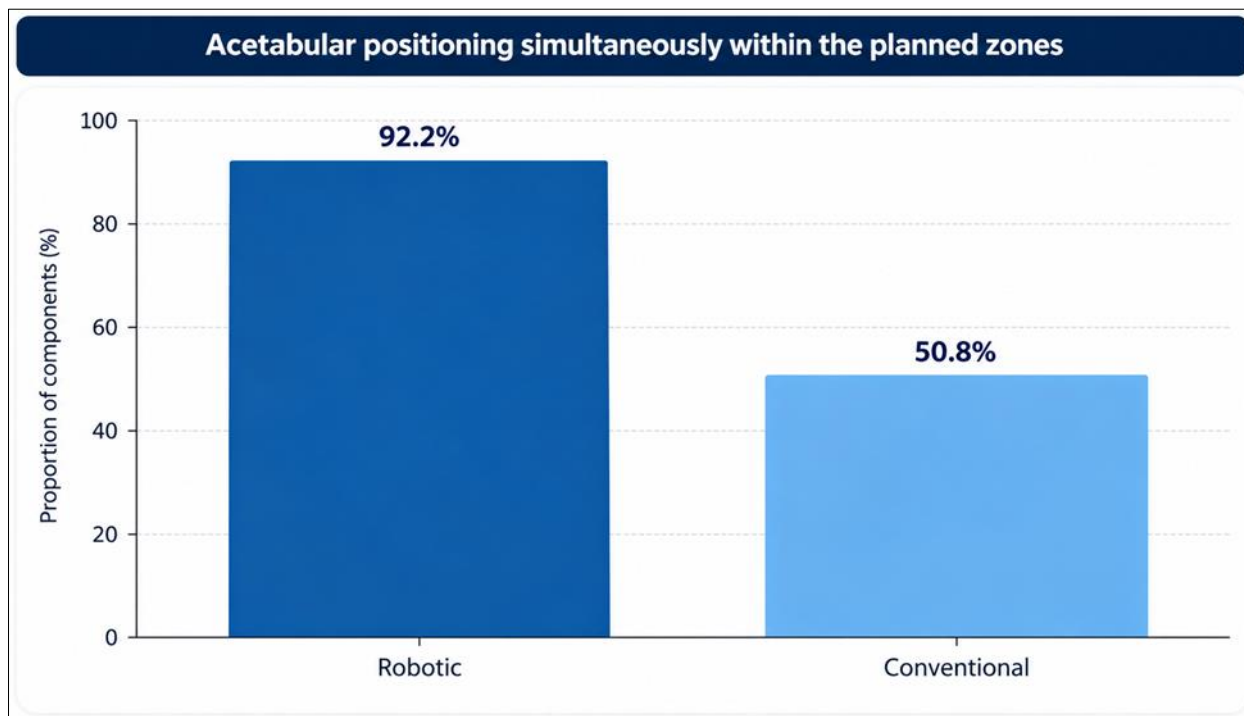
Source: prepared by the authors based on Lu *et al.* (2024), Mostafa *et al.* (2025) ^[8], Geng *et al.* (2025) ^[3], Bensa *et al.* (2025) ^[1], Klincke *et al.* (2026) ^[6], and Giovanoulis *et al.* (2026) ^[4].

Fig 1: Sample size of the main studies included in the review.

Despite technical advances, the central question is no longer merely whether the robot can execute the plan more accurately, but whether this additional accuracy produces a benefit perceived by the patient. Mostafa *et al.* (2025) ^[8] and Klincke *et al.* (2026) ^[6] observed radiographic superiority with robotic TKA, but small or absent differences in several patient-reported outcomes. Similarly, Bensa *et al.* (2025) ^[1] demonstrated greater positioning accuracy in THA without consistent overall clinical superiority.

In THA, two findings objectively illustrate this technical

superiority. Geng *et al.* (2025) ^[3] found that 92.2% of acetabular components in the robotic group were simultaneously within the planned inclination and anteversion zones, compared with 50.8% in the conventional group. Lu *et al.* (2024) ^[7], in turn, observed a mean limb-length discrepancy of 2.87 mm with robotics and 5.81 mm with the conventional technique. These results are presented in Graph 2 and indicate that the main proven advantage of robotics remains, to date, predominantly technical and radiographic.

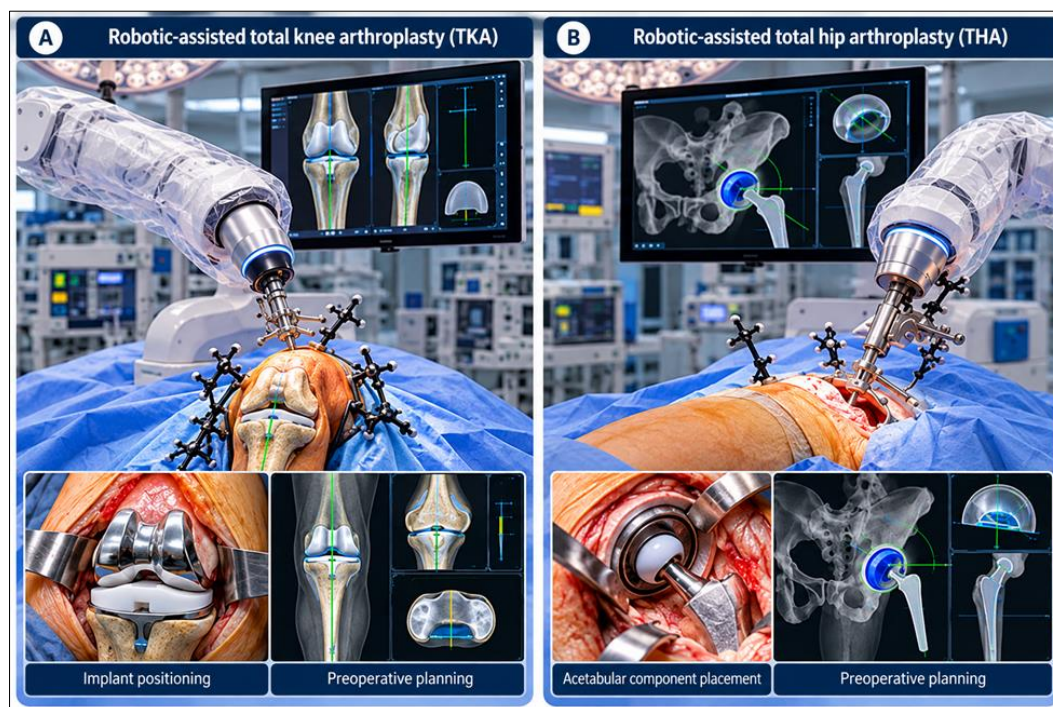


Source: prepared by the authors based on Geng *et al.* (2025) [3].

Fig 2: Acetabular positioning within the planned zones: robotic versus conventional technique.

Figure 3 illustrates the use of robotic systems in total knee and hip arthroplasty. The image highlights the integration of digital planning, image monitoring, and robotic-arm operation during the surgical procedure, emphasizing parameters such as alignment, prosthetic component positioning, and biomechanical reconstruction. In the knee, the technology aims to increase the accuracy of bone cuts and

prosthetic alignment, whereas in the hip it allows greater control of acetabular orientation and implant positioning. Thus, the figure summarizes the role of robotics as a support tool for surgical execution, contributing to greater standardization, accuracy, and reproducibility of the procedures.



Source: AI-generated scientific illustration, 2026. For illustrative purposes only; not an actual surgical procedure.

Fig 3: Robotic-assisted total knee and hip arthroplasty: surgical planning and implant positioning.

- (A) Robotic-assisted total knee arthroplasty (TKA), illustrating intraoperative navigation, component positioning, and digital planning of lower-limb alignment.
- (B) Robotic-assisted total hip arthroplasty (THA), demonstrating robotic guidance for acetabular component placement and three-dimensional preoperative planning.

Another relevant aspect is that robotics does not represent a homogeneous technology. Platforms differ regarding the need for preoperative computed tomography, the method of anatomical registration, degree of automation, possibility of dynamic planning, and alignment strategy. These differences limit direct generalization of results from one platform to another and reinforce the need to interpret studies according to the system used and the surgical context.

Challenges also remain regarding acquisition and maintenance costs, training, the learning curve, and longer operative time. Mostafa *et al.* (2025)^[8] observed an average increase of nearly 20 minutes in robotic TKA, whereas Lu *et al.* (2024)^[7] reported longer procedure duration in robotic THA. Therefore, technology assessment should combine accuracy, clinical outcomes, safety, efficiency, and economic sustainability.

In this context, an updated synthesis of the evidence is needed to distinguish technically demonstrated benefits from clinical advantages that have not yet been established. This review seeks to integrate findings from clinical trials, prospective studies, and recent meta-analyses, critically examining the contribution of robotic surgery to accuracy, function, safety, and the future of total knee and hip arthroplasty.

2. Rationale

Total knee and hip arthroplasties are procedures of major functional relevance, and small deviations in prosthetic positioning or biomechanical reconstruction may compromise stability, kinematics, wear, and satisfaction. Robotics was developed precisely to reduce technical variability; however, its cost and complexity require a careful assessment of its real effectiveness.

Recent literature shows a recurring pattern: relatively consistent radiographic superiority and less uniform clinical superiority. This contrast has implications for surgeons, managers, hospital services, and patients, because the incorporation of high-cost technologies should be supported not only by greater accuracy, but also by relevant clinical outcomes, safety, durability, and potential cost-effectiveness (BENSA *et al.*, 2025; KLINCKE *et al.*, 2026)^[1, 6].

This review is therefore justified by the need to gather contemporary evidence and critically compare the main outcomes of robotic TKA and THA, identifying proven benefits, current limitations, knowledge gaps, and perspectives for treatment personalization.

3. Objectives

3.1. General Objective

To critically analyze recent evidence on the use of robotic surgery in total knee and hip arthroplasty, comparing it with conventional techniques in terms of surgical accuracy, clinical and functional outcomes, safety, complications, revisions, and perioperative aspects.

3.2. Specific Objectives

Compare the accuracy of prosthetic component positioning between robotic and conventional techniques;

Assess alignment, the occurrence of outliers, and reproducibility of surgical planning;

Analyze pain, range of motion, function, satisfaction, quality of life, and other patient-reported outcomes;

Compare complication, adverse-event, and revision rates;

Assess operative time, blood loss, and other perioperative parameters;

Examine biomechanical restoration in total hip arthroplasty; Analyze individualized alignment strategies in total knee arthroplasty;

Identify limitations related to costs, the learning curve, platform heterogeneity, and lack of long-term follow-up;

Identify gaps and future perspectives for robotic surgery in arthroplasty.

4. Methods

The study was developed as a descriptive and analytical systematic review, structured according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020), with the objective of identifying, selecting, and critically synthesizing recent evidence on robotic surgery in total knee and hip arthroplasty (PAGE *et al.*, 2021)^[9].

The research question was organized using the PICO strategy. The population (P) comprised adults undergoing primary total knee or hip arthroplasty; the intervention (I), robot-assisted surgery; the comparator (C), conventional or manual technique; and the outcomes (O), positioning accuracy, alignment, clinical and functional outcomes, pain, satisfaction, complications, revisions, operative time, blood loss, length of stay, and implementation aspects.

The literature search was planned for PubMed/MEDLINE, Scopus, Web of Science, Cochrane Library, Virtual Health Library, and SciELO, considering publications from January 2021 to September 2026. Controlled descriptors and free-text terms related to robotic surgery, robot-assisted surgery, total knee arthroplasty, total hip arthroplasty, alignment, component positioning, clinical outcomes, functional outcomes, and complications were combined using the Boolean operators AND and OR.

Eligible studies included randomized clinical trials, comparative prospective or retrospective studies, cohort studies, systematic reviews, and meta-analyses in adults undergoing primary robotic TKA or THA, provided that at least one outcome related to accuracy, function, safety, revision, or perioperative parameters was reported. Case reports, very small case series, editorials, opinions, exclusively cadaveric or computational studies, publications before 2021, and studies without clinically interpretable results were excluded.

Selection was organized into identification, duplicate removal, title and abstract screening, full-text assessment, and final inclusion. From the selected studies, the following data were extracted: author, year, design, sample, procedure, alignment strategy when applicable, main radiographic measurements, clinical outcomes, complications, and perioperative information. Synthesis was predominantly narrative, with findings organized in comparative tables.

Interpretation of the results prioritized the distinction between statistical significance and clinical relevance. Thus, accuracy advantages were analyzed separately from functional scores and patient-reported outcomes, avoiding conclusions of clinical superiority based solely on radiographic improvement.

Because the study used only published, scientifically accessible data, with no contact with participants and no use of identifiable individual data, submission to a Research Ethics Committee was not required.

5. Results

The synthesis of the studies demonstrated a consistent pattern of greater technical accuracy with robotic assistance in both

TKA and THA. However, the magnitude of clinical benefits varied according to the outcome, alignment strategy, follow-up duration, and assessment instrument. To facilitate comparison of the main results, the studies were organized into six thematic tables presented below.

5.1. Total Knee Arthroplasty: Accuracy and Alignment

In TKA, the most consistent findings were related to reducing deviations from the surgical plan. Mostafa *et al.* (2025)^[8], in a systematic review and meta-analysis of 21 randomized clinical trials including 2,692 patients, demonstrated fewer mechanical-alignment outliers with the robotic technique, with a relative risk of 0.33. Despite radiographic superiority,

there was no significant difference in WOMAC or Oxford Knee Score.

Klincke *et al.* (2026)^[6], in a meta-analysis of 20 prospective studies including 2,421 patients, also observed greater coronal-alignment accuracy, better restoration of the joint line, and fewer deviations. Giovanoulis *et al.* (2026)^[4] added favorable evidence for robotic functional alignment, indicating high execution accuracy and a low early revision rate.

Table 1 summarizes the main studies related to accuracy and alignment in robotic TKA, showing that the technical advantage is more consistent than the clinical advantage.

Table 1: Main studies related to accuracy and alignment in total knee arthroplasty

Author/year	Design/sample	Main results
Mostafa <i>et al.</i> (2025) ^[8]	Meta-analysis of 21 RCTs; 2,692 patients	Fewer mechanical-alignment outliers; RR 0.33; less deviation from the neutral axis; no consistent superiority in WOMAC or OKS.
Klincke <i>et al.</i> (2026) ^[6]	Meta-analysis of 20 prospective studies; 2,421 patients	Better coronal alignment, restoration of the joint line, and fewer deviations; modest clinical gains.
Giovanoulis <i>et al.</i> (2026) ^[4]	Systematic review and meta-analysis	High accuracy in functional-alignment execution and favorable radiographic outcomes.

Source: prepared by the authors based on Mostafa *et al.* (2025)^[8], Klincke *et al.* (2026)^[6], and Giovanoulis *et al.* (2026)^[4].

5.2. Clinical and Functional Outcomes in Total Knee Arthroplasty

Functional outcomes were more heterogeneous than radiographic outcomes. Mostafa *et al.* (2025)^[8] found no significant differences in WOMAC or Oxford Knee Score, although a small advantage was observed in the Knee Society Score. Klincke *et al.* (2026)^[6] found improved range of motion and some WOMAC components, but no significant differences in OKS, KOOS, FJS, or EQ-5D.

Individualized alignment strategies showed potentially more favorable findings. Garg *et al.* (2026)^[2], evaluating 12 studies

and 1,470 patients, observed better Oxford Knee Score, Forgotten Joint Score, and range of motion with robotic kinematic alignment than with mechanical alignment. Jamaledine *et al.* (2026)^[5] demonstrated less need for soft-tissue releases and more favorable early functional recovery with functional alignment, but no sustained superiority at one year.

Table 2 compares the main clinical outcomes and reinforces that the functional benefit tends to be modest, variable, and possibly more dependent on the alignment strategy than on the simple use of a robotic platform.

Table 2: Main studies on functional outcomes in robotic knee arthroplasty

Author/year	Population	Main clinical findings
Mostafa <i>et al.</i> (2025) ^[8]	2,692 patients	No relevant differences in WOMAC or OKS; small improvement in KSS.
Klincke <i>et al.</i> (2026) ^[6]	2,421 patients	Improved ROM and some WOMAC components; no difference in OKS, KOOS, FJS, or EQ-5D.
Garg <i>et al.</i> (2026) ^[2]	1,470 patients	Kinematic alignment showed better OKS, FJS, and ROM than mechanical alignment.
Jamaledine <i>et al.</i> (2026) ^[5]	645 TKAs	Fewer soft-tissue releases and better early functional recovery; no sustained superiority at one year.

Source: prepared by the authors based on Mostafa *et al.* (2025)^[8], Klincke *et al.* (2026)^[6], Garg *et al.* (2026)^[2], and Jamaledine *et al.* (2026)^[5].

5.3. Complications, Revisions, and Early Survivorship in Knee Arthroplasty

Assessment of complications and revisions did not indicate increased risk with the use of robotics. Giovanoulis *et al.* (2026)^[4] identified 18 aseptic revisions among 5,155 robotic TKAs performed according to functional-alignment principles, corresponding to approximately 0.35%. This finding suggests favorable early performance, although the

available follow-up remains insufficient to infer superiority in long-term implant survivorship.

Klincke *et al.* (2026)^[6] observed a lower overall frequency of complications in some analyses, whereas Mostafa *et al.* (2025)^[8] found no relevant increase in adverse events despite longer operative time. Table 3 brings together these results and shows that the safety of the technique appears comparable to the conventional approach in the short term.

Table 3: Complications and early survivorship in robotic knee arthroplasty

Author/year	Sample	Results
Giovanoulis <i>et al.</i> (2026) ^[4]	5,155 TKAs	18 aseptic revisions; approximately 0.35%; good functional scores and a low complication rate.
Klincke <i>et al.</i> (2026) ^[6]	2,421 patients	Lower overall complication frequency in some analyses.
Mostafa <i>et al.</i> (2025) ^[8]	2,692 patients	No relevant increase in complications; longer robotic procedure duration.

Source: prepared by the authors based on Giovanoulis *et al.* (2026)^[4], Klincke *et al.* (2026)^[6], and Mostafa *et al.* (2025)^[8].

5.4. Total hip arthroplasty: accuracy and biomechanical reconstruction

In THA, technical superiority was demonstrated by multicenter clinical trials. Lu *et al.* (2024)^[7], in a randomized study of 148 patients, observed a mean limb-length discrepancy of 2.87 mm in the robotic group and 5.81 mm in the conventional group, as well as lower femoral-stem angulation. However, there was no significant difference in Harris Hip Score or pain intensity.

Geng *et al.* (2025)^[3], in a randomized clinical trial of 138

patients, found that 92.2% of acetabular components in the robotic group were simultaneously within the planned inclination and anteversion zones, compared with 50.8% in the conventional group. Bensa *et al.* (2025)^[1], in a meta-analysis of 38 studies and 10,055 patients, confirmed greater accuracy of acetabular positioning and better adherence to safe zones.

Table 4 presents these studies and shows that the strongest effects of robotics in THA are related to geometric and biomechanical control of the reconstruction.

Table 4: Main studies on accuracy in total hip arthroplasty

Author/year	Design/sample	Main results
Lu <i>et al.</i> (2024) ^[7]	Multicenter RCT; 148 patients	Lower limb-length discrepancy (2.87 vs. 5.81 mm) and lower femoral angulation with robotics.
Geng <i>et al.</i> (2025) ^[3]	Multicenter RCT; 138 patients	92.2% of components within the planned parameters versus 50.8% with the conventional technique.
Bensa <i>et al.</i> (2025) ^[1]	Meta-analysis; 38 studies; 10,055 patients	Greater acetabular accuracy and better positioning within the safe zone.

Source: prepared by the authors based on Lu *et al.* (2024)^[7], Geng *et al.* (2025)^[3], and Bensa *et al.* (2025)^[1].

5.5. Clinical and Functional Outcomes in Total Hip Arthroplasty

Radiographic improvement was not accompanied by uniform clinical superiority. Lu *et al.* (2024)^[7] found no significant difference in Harris Hip Score or pain despite better restoration of limb length. Geng *et al.* (2025)^[3], even with a marked advantage in acetabular positioning, did not identify

significant improvement in WOMAC, Harris Hip Score, or SF-36 during early follow-up.

The meta-analysis by Bensa *et al.* (2025)^[1] reinforced the dissociation between accuracy and function, demonstrating that robotics consistently improves component placement but does not produce overall superiority in the main PROMs. Table 5 summarizes these findings.

Table 5: Main studies on clinical outcomes in hip arthroplasty

Author/year	Clinical assessment	Result
Lu <i>et al.</i> (2024) ^[7]	HHS and VAS	No significant clinical difference between robotic and manual techniques.
Geng <i>et al.</i> (2025)	WOMAC, HHS e SF-36	No significant difference despite greater acetabular accuracy.
Bensa <i>et al.</i> (2025) ^[1]	HHS, WOMAC, FJS, and other PROMs	Greater radiographic accuracy without overall clinical superiority.

Source: prepared by the authors based on Lu *et al.* (2024)^[7], Geng *et al.* (2025)^[3], and Bensa *et al.* (2025)^[1].

5.6. Safety and Perioperative Aspects

Operative time was the most consistent perioperative limitation. Mostafa *et al.* (2025)^[8] identified a mean increase of approximately 19.94 minutes in robotic TKA. In THA, Lu *et al.* (2024)^[7] observed a mean operative time of 106.7 minutes in the robotic group and 79.4 minutes in the conventional group. Geng *et al.* (2025)^[3] also identified

longer procedure duration, without a relevant increase in adverse events.

In contrast, blood loss and overall complication rates did not show consistent worsening with the technology. Table 6 summarizes perioperative safety and efficiency and suggests that the main immediate operational cost of robotics is longer procedure duration, especially during the learning curve.

Table 6: Safety and perioperative aspects

Author/year	Procedure	Main findings
Mostafa <i>et al.</i> (2025) ^[8]	TKA	Increase of approximately 20 minutes in operative time; no significant difference in blood loss.
Lu <i>et al.</i> (2024) ^[7]	THA	106.7 min with robotics versus 79.4 min with the conventional technique; no demonstrated safety disadvantage.
Geng <i>et al.</i> (2025)	THA	Longer operative time; similar adverse-event rates.
Bensa <i>et al.</i> (2025) ^[1]	THA	Greater accuracy with a safety profile comparable to the conventional technique.

Source: prepared by the authors based on Mostafa *et al.* (2025)^[8], Lu *et al.* (2024)^[7], Geng *et al.* (2025)^[3], and Bensa *et al.* (2025)^[1].

5.7. Integrated Synthesis of The Results

Integration of the findings demonstrates three main patterns. First, the technical superiority of robotics is consistent: there is less variability, greater adherence to planning, and better control of anatomical parameters. Second, clinical superiority is less evident: many studies identify similar functional outcomes despite marked radiographic differences. Third, safety appears comparable to the conventional technique, but

longer operative time, costs, and the learning curve remain important limitations.

In TKA, robotics appears particularly promising when used for personalized alignment strategies, such as kinematic and functional alignment. In THA, the most robust benefit lies in acetabular positioning and biomechanical reconstruction. In both procedures, there is still insufficient evidence to

conclude that robotics increases long-term implant survivorship.

6. Discussion

The results of this review show that robotic surgery has reached a stage in which its ability to increase surgical accuracy is well documented. The current controversy has therefore shifted from the question “is the robot more accurate?” to a more clinically relevant question: “does this additional accuracy improve the patient’s life in a noticeable and lasting way?”. This distinction is essential to prevent radiographic outcomes from being interpreted, in isolation, as evidence of clinical superiority.

In TKA, Mostafa *et al.* (2025)^[8] showed a marked reduction in mechanical-alignment outliers but no significant difference in WOMAC or Oxford Knee Score. Klincke *et al.* (2026)^[6] reached a similar conclusion, although they identified small advantages in range of motion and some WOMAC components. The convergence of these findings suggests that radiographic accuracy represents a real benefit, but its functional translation may be limited by the high effectiveness already achieved by conventional techniques.

An important hypothesis is that the greatest utility of robotics lies in personalization rather than in simply reproducing a uniform mechanical target. Garg *et al.* (2026)^[2] observed better outcomes with robotic kinematic alignment, whereas Jamaledine *et al.* (2026)^[5] found early advantages of functional alignment, especially less need for soft-tissue release and better initial mobility. These findings support the idea that robotic platforms may enable reconstructions that more closely reflect individual anatomy and kinematics.

However, the benefits of personalized strategies still require cautious interpretation. Jamaledine *et al.* (2026)^[5] demonstrated that initial functional differences decreased over follow-up, becoming similar at one year. This suggests that some gains may accelerate recovery without necessarily changing late outcomes. Future studies should assess not only mean scores but also minimal clinically important difference, time to functional recovery, and the proportion of patients who achieve acceptable symptomatic states.

The low early revision rate observed by Giovanoulis *et al.* (2026)^[4], approximately 0.35% among 5,155 TKAs, is encouraging. However, the available mean follow-up does not yet allow the conclusion that greater accuracy reduces loosening, polyethylene wear, or late failures. The relationship between alignment and implant longevity is complex and depends on mechanical, biological, activity-related, and implant-design factors.

In THA, the dissociation between accuracy and function was even more evident. Lu *et al.* (2024)^[7] demonstrated less limb-length discrepancy and better control of the femoral stem, whereas Geng *et al.* (2025)^[3] observed a marked difference in the proportion of acetabular components positioned within the planned zones. Nevertheless, neither study found significant superiority in the main clinical scores. Bensa *et al.* (2025)^[1], analyzing more than ten thousand patients, confirmed this pattern on a larger scale.

This phenomenon may be explained, in part, by the so-called ceiling effect. Patients treated with modern conventional techniques can already achieve high levels of pain relief and functional improvement, reducing the margin for robotics to demonstrate additional advantages on traditional scales. More subtle benefits, such as a perception of a more natural joint, symmetry, confidence, return to specific activities, or

lower variability among surgeons, may not be fully captured by some clinical instruments.

Another consideration is technological heterogeneity. Robotic systems vary in computed-tomography-based planning, navigation, imageless registration, execution limits, interfaces, and degree of active instrument control. Consequently, “robotic surgery” should not be treated as a single intervention. Meta-analyses that pool different platforms may increase statistical power but may also dilute relevant differences among technologies.

Longer operative time was a recurring finding. Mostafa *et al.* (2025)^[8] identified an increase of nearly 20 minutes in TKA; Lu *et al.* (2024)^[7] observed an even greater difference in THA. Part of this penalty may decrease with experience, workflow optimization, and team integration, but its impact should be considered in high-volume centers, where additional minutes per procedure may affect productivity and costs.

The economic discussion is unavoidable. Robotics involves initial investment, maintenance, consumables, training, and potential platform dependence. In return, hypothetical benefits such as fewer revisions, lower complication rates, fewer outliers, and greater predictability could offset part of these costs over time. The problem is that most available evidence still focuses on early and intermediate outcomes, making definitive cost-effectiveness models difficult.

From a clinical perspective, selective adoption may be more rational than indiscriminate use. Patients with complex deformities, altered anatomy, major limb-length discrepancy, a need for precise three-dimensional planning, or personalized alignment strategies may represent groups in which the technology offers greater incremental value. This hypothesis, however, needs to be tested prospectively.

The limitations of this review include the relatively small number of directly comparable studies, heterogeneity of the platforms, variation in clinical scores, differences in follow-up duration, and the combined inclusion of systematic reviews, meta-analyses, and clinical trials. Even so, the consistency of accuracy findings across different study designs strengthens the conclusion that robotics reduces technical variability.

Future research should prioritize randomized multicenter trials, medium- and long-term follow-up, standardization of PROMs, assessment of minimal clinically important difference, subgroup analyses, revision registries, and economic studies. It will also be important to directly compare personalized alignment strategies and assess whether the technology reduces dependence on surgeon experience or merely improves execution in already specialized hands.

In summary, robotics should not be interpreted as a substitute for surgical judgment, but as a tool capable of expanding planning, measurement, and reproducibility. Its greatest potential appears to lie in the integration of accuracy and personalization. Demonstrating that this potential translates into better function, satisfaction, and implant longevity will define its definitive role in modern arthroplasty.

7. Conclusion

The evidence analyzed indicates that robotic surgery represents a relevant technological advance in total knee and hip arthroplasty, mainly by increasing accuracy, reducing deviations from the plan, and expanding the ability to perform individualized reconstruction. In TKA, the most

consistent benefits are concentrated in alignment and reduction of outliers; in THA, acetabular positioning, control of limb length, and biomechanical restoration stand out. Greater accuracy, however, does not uniformly translate into clinical superiority. Functional scores, pain, and quality of life often remain similar to those obtained with conventional techniques, although some personalized alignment strategies show promising results, especially in early recovery. Robotic safety was comparable to the conventional approach, with no consistent evidence of increased complications. Longer operative time, implementation costs, the learning curve, and heterogeneity among platforms remain important limitations.

It is concluded that robotic surgery offers a proven advantage in accuracy and reproducibility, but its overall clinical superiority and its impact on implant survivorship have not yet been definitively established. The future of the technology will likely depend on identifying the patients who truly benefit from personalization, demonstrating cost-effectiveness, and obtaining long-term evidence on revision, function, and satisfaction.

References

1. Bensa A, Pagliazzi G, Miele A, Schiavon G, Cuzzolin M, Filardo G. Robotic-assisted total hip arthroplasty provides greater implant placement accuracy and lower complication rates, but not superior clinical results compared to the conventional manual approach: a systematic review and meta-analysis. *J Arthroplasty*. 2025;40(7):1921-1931. doi:10.1016/j.arth.2024.12.014.
2. Garg N, Gupta N, Khatri K, Bansal N, Bansal K, Passi A. Functional, patient-reported, and radiographic outcomes of kinematic versus mechanical alignment in robotic total knee arthroplasty: a systematic review and meta-analysis. *Knee*. 2026;60:104412. doi:10.1016/j.knee.2026.104412.
3. Geng X, Dong Z, Li Y, Zhao M, Liu Y, Li Z, *et al*. Precise acetabular prosthesis positioning using a novel robot-assisted total hip arthroplasty system: a multicenter, randomized controlled trial. *Orthop Surg*. 2025;17(1):141-150. doi:10.1111/os.14277.
4. Giovanoulis V, Vasiliadis AV, Andriollo L, Gregori P, Dretakis K, Koutserimpas C, *et al*. Functional alignment in robotic total knee arthroplasty provides favourable outcomes and minimal early revisions: a systematic review and meta-analysis. *Knee Surg Sports Traumatol Arthrosc*. 2026;34(9):3362-3376. doi:10.1002/ksa.70226.
5. Jamaledine Y, Maroun R, Assi C, Khoury A, Kouyoumdjian P. Functional versus mechanical alignment in robotic primary total knee arthroplasty: a meta-analysis. *SICOT J*. 2026;12:50. doi:10.1051/sicotj/2026061.
6. Klincke V, Huyghe R, Vermue H, Martens M, Victor J. Robot-assisted total knee arthroplasty demonstrates superior radiological but comparable clinical outcomes compared to conventional techniques: a meta-analysis of prospective studies. *Knee Surg Sports Traumatol Arthrosc*. 2026;34(2):618-632. doi:10.1002/ksa.70007.
7. Lu X, Zhang Z, Xu H, Wang W, Zhang H. A new designed full process coverage robot-assisted total hip arthroplasty: a multicentre randomized clinical trial. *Int J Surg*. 2024;110(4):2141-2150. doi:10.1097/JS9.0000000000001103.
8. Mostafa O, Malik M, Qayum K, Ishaq U, Khan AM, Wasim AS, *et al*. Robotic-assisted versus conventional total knee arthroplasty: a systematic review and meta-analysis of alignment accuracy and clinical outcomes. *Ann Med Surg (Lond)*. 2025;87(2):867-879. doi:10.1097/MS9.0000000000002919.
9. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, *et al*. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*. 2021;372:n71. doi:10.1136/bmj.n71.

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