Research Article

Comparative Functional Outcomes of Robotic-Assisted vs Conventional Total Knee Arthroplasty: A Prospective Study

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ABSTRACT

Background: Total knee arthroplasty (TKA) is an established surgical procedure for advanced knee osteoarthritis. Robotic-assisted TKA has been introduced to improve implant positioning accuracy and surgical precision. However, whether these technical advantages translate into superior functional outcomes remains under evaluation.

Methods: This prospective comparative study was conducted at Lifeline Superspeciality Hospital over one year. A total of 80 patients undergoing primary TKA were included and divided into two groups: 40 patients underwent robotic-assisted TKA and 40 underwent conventional TKA. Baseline demographic characteristics were comparable between groups. Perioperative parameters, radiological alignment, and functional outcomes were assessed using Knee Society Score (KSS), WOMAC score, and range of motion (ROM) at regular follow-up intervals up to one year. Statistical analysis was performed with significance set at p < 0.05.

Results: The robotic group demonstrated significantly better mechanical axis alignment ($1.2 \pm 0.9°$ vs $2.8 \pm 1.5°$, p = 0.001) and fewer alignment outliers (5% vs 20%, p = 0.04). Mean blood loss was lower in the robotic group (310 ± 55 ml vs 380 ± 70 ml, p = 0.002), although operative time was longer (108 ± 12 min vs 92 ± 10 min, p = 0.001). At one year, the robotic group showed higher KSS (89.4 ± 5.8 vs 84.7 ± 6.6, p = 0.003), lower WOMAC scores (14.8 ± 5.2 vs 18.6 ± 6.4, p = 0.01), and greater ROM ($122.4 \pm 8.6°$ vs $116.8 \pm 9.3°$, p = 0.004). Complication rates were comparable between groups.

Conclusion: Robotic-assisted TKA demonstrated superior alignment precision and improved functional outcomes at one year compared to conventional TKA, despite increased operative time. These findings support the role of robotic technology in enhancing surgical accuracy and early functional recovery.

Keywords: Robotic-assisted total knee arthroplasty, Conventional TKA, Functional outcomes, Knee Society Score, Mechanical alignment, Osteoarthritis.

INTRODUCTION

Total knee arthroplasty (TKA) is widely regarded as one of the most successful orthopaedic procedures for the management of advanced knee osteoarthritis, providing substantial pain relief and functional improvement in affected patients [1]. With increasing life expectancy and rising prevalence of degenerative joint disease, the global demand for TKA has expanded significantly over the past two decades [2]. In India as well, osteoarthritis of the knee represents a major cause of disability among middle-aged and elderly individuals, leading to a steady rise in primary TKA procedures across tertiary care centers [3].

Despite the high success rates of conventional TKA, up to 15–20% of patients report dissatisfaction due to persistent pain, limited function, or altered joint kinematics [4]. Malalignment, imprecise bone cuts, and variability in component positioning have been identified as potential contributors to suboptimal outcomes [5]. These limitations have driven the development of technology-assisted surgical systems aimed at improving accuracy and reproducibility.

Robotic-assisted total knee arthroplasty (RA-TKA) was introduced to enhance precision in implant positioning and soft tissue balancing. Early investigations demonstrated improved component alignment and reduced outliers compared with conventional jig-based techniques [6]. Subsequent clinical studies suggested that robotic systems may allow better restoration of mechanical axis and joint line, potentially translating into improved early functional recovery [7]. Furthermore, advances in semi-active robotic platforms have been associated with reduced soft tissue trauma and improved early postoperative pain scores [8].

Although radiological superiority of robotic systems has been increasingly reported, the evidence regarding long-term functional outcomes remains evolving. Given the additional cost, learning curve, and operative time associated with robotic platforms, it is essential to evaluate whether these technological advantages translate into clinically meaningful improvements in patient-reported and functional outcomes.

Therefore, the present prospective study was undertaken at Lifeline Superspeciality Hospital over a one-year period to compare functional outcomes between robotic-assisted and conventional total knee arthroplasty in a cohort of 80 patients (40 robotic and 40 conventional). This study aims to contribute evidence from a tertiary care setting to clarify the comparative effectiveness of these two surgical approaches.

The aim of this prospective study is to compare the functional outcomes of robotic-assisted total knee arthroplasty with conventional total knee arthroplasty in patients undergoing surgery at a tertiary care center. The objectives are to evaluate postoperative functional scores, range of motion, pain levels, implant alignment accuracy, complication rates, and early recovery parameters between the two groups over a one-year follow-up period. The justification for the study lies in the increasing adoption of robotic systems in joint replacement surgery, despite their higher cost and learning curve, with limited clarity regarding whether improved surgical precision translates into superior clinical outcomes. The expected future outcomes of this study include providing evidence-based guidance on the clinical effectiveness of robotic-assisted TKA, supporting decision-making for surgeons and healthcare institutions, and contributing to optimization of surgical strategies to enhance patient satisfaction and long-term functional performance.

METHODOLOGY

This prospective comparative study was conducted at Lifeline Superspeciality Hospital over a period of one year. Institutional ethical committee approval was obtained prior to the commencement of the study. Written informed consent was secured from all participants after explaining the nature of the procedure, potential risks, benefits, and follow-up protocol.

A total of 80 patients diagnosed with advanced primary osteoarthritis of the knee and indicated for total knee arthroplasty were included in the study. The participants were divided into two groups comprising 40 patients who underwent robotic-assisted total knee arthroplasty (RA-TKA) and 40 patients who underwent conventional total knee arthroplasty (C-TKA). Allocation was performed based on preoperative surgical planning and patient preference after counseling regarding both techniques.

Patients aged above 45 years with radiographically confirmed Grade III or IV osteoarthritis of the knee who were fit for surgery were included in the study. Patients undergoing revision TKA, those with inflammatory arthritis, post-traumatic arthritis, severe fixed deformities requiring constrained implants, active joint infection, neuromuscular disorders, or uncontrolled systemic comorbidities were excluded.

A comprehensive preoperative assessment was carried out for all patients. Demographic data including age, gender, body mass index, and comorbidities were recorded. Baseline functional evaluation was performed using standardized scoring systems such as the Knee Society Score (KSS) and range of motion assessment with a goniometer. Preoperative radiographs including standing anteroposterior, lateral, and long-leg alignment views were obtained to assess deformity and mechanical axis.

All surgeries were performed by experienced orthopedic surgeons trained in both techniques. In the robotic-assisted group, a semi-active robotic platform was utilized for preoperative planning, bone resection guidance, and implant positioning. In the conventional group, standard intramedullary and extramedullary alignment guides were used for bone cuts and component placement. Intraoperative parameters including operative time, estimated blood loss, and any complications were documented.

Postoperatively, all patients followed a standardized rehabilitation protocol. Early mobilization with quadriceps strengthening exercises and assisted ambulation was initiated on the first postoperative day. Pain was managed using a multimodal analgesic regimen. Thromboprophylaxis and antibiotic prophylaxis were administered as per institutional protocol.

Patients were followed up at 6 weeks, 3 months, 6 months, and 1 year postoperatively. At each follow-up visit, functional outcomes were assessed using validated scoring systems, range of motion measurements, and radiographic evaluation of component alignment and mechanical axis. Complications such as infection, stiffness, implant loosening, thromboembolic events, or need for revision were recorded.

All collected data were entered into a structured database and analyzed using appropriate statistical software. Continuous variables were expressed as mean ± standard deviation, while categorical variables were expressed as frequency and percentage. Independent t-test and chi-square test were applied for comparison between groups. A p-value of less than 0.05 was considered statistically significant.

RESULTS

A total of 80 patients were included in this prospective study, with 40 patients undergoing robotic-assisted total knee arthroplasty (TKA) and 40 undergoing conventional TKA. The mean age in the robotic group was 64.8 ± 6.9 years compared to 65.2 ± 7.4 years in the conventional group, showing no statistically significant difference (p = 0.78). Females constituted 55% of the robotic group and 57.5% of the conventional group. The mean body mass index (BMI) was comparable between groups (28.6 ± 3.2 kg/m² vs 28.9 ± 3.6 kg/m², p = 0.69). Preoperative functional status was similar, with mean preoperative Knee Society Score (KSS) of 42.5 ± 8.4 in the robotic group and 43.1 ± 7.9 in the conventional group (p = 0.71). Baseline range of motion (ROM) was 92.4 ± 12.3° and 90.6 ± 11.8° respectively (p = 0.49), indicating homogeneity between the two groups before intervention.

Regarding perioperative parameters, the mean operative time was significantly longer in the robotic group (108 ± 12 minutes) compared to the conventional group (92 ± 10 minutes) (p = 0.001). However, the robotic group demonstrated significantly lower mean intraoperative blood loss (310 ± 55 ml vs 380 ± 70 ml, p = 0.002). Radiological assessment showed superior mechanical axis restoration in the robotic group, with mean deviation of 1.2 ± 0.9° compared to 2.8 ± 1.5° in the conventional group (p = 0.001). Alignment outliers (>3° deviation) were observed in 5% of robotic cases compared to 20% in the conventional group (p = 0.04). The average hospital stay was shorter in the robotic group (4.8 ± 1.2 days) compared to 5.6 ± 1.5 days in the conventional group (p = 0.03).

Functional outcomes at follow-up demonstrated statistically significant superiority in the robotic group. At 6 months, the mean KSS was 82.6 ± 6.4 in the robotic group compared to 78.9 ± 7.1 in the conventional group (p = 0.01). At 1 year, the robotic group achieved a higher mean KSS of 89.4 ± 5.8 versus 84.7 ± 6.6 in the conventional group (p = 0.003). The mean 1-year WOMAC score was significantly lower (indicating better outcome) in the robotic group (14.8 ± 5.2) compared to the conventional group (18.6 ± 6.4) (p = 0.01). Additionally, postoperative ROM at 1 year was significantly greater in the robotic group (122.4 ± 8.6° vs 116.8 ± 9.3°, p = 0.004). Although anterior knee pain was lower in the robotic group (7.5%) compared to the conventional group (20%), this difference did not reach statistical significance (p = 0.09). No revisions were observed in the robotic group, while one revision (2.5%) occurred in the conventional group during the one-year follow-up.

Overall, robotic-assisted TKA demonstrated improved radiological alignment, reduced blood loss, shorter hospital stay, and superior functional outcomes at one year compared to conventional TKA, despite a longer operative time.

Table 1. Demographic and Baseline Characteristics

Variable	Robotic TKA (n=40)	Conventional TKA (n=40)	p-value
Mean Age (years)	64.8 ± 6.9	65.2 ± 7.4	0.78
Gender (Male)	18 (45%)	17 (42.5%)	0.82
Gender (Female)	22 (55%)	23 (57.5%)	
Mean BMI (kg/m²)	28.6 ± 3.2	28.9 ± 3.6	0.69
Right Knee (%)	24 (60%)	26 (65%)	0.64
Left Knee (%)	16 (40%)	14 (35%)	
Pre-op KSS Score	42.5 ± 8.4	43.1 ± 7.9	0.71
Pre-op WOMAC Score	68.2 ± 9.6	67.5 ± 8.9	0.74
Pre-op ROM (°)	92.4 ± 12.3	90.6 ± 11.8	0.49

Table 2. Perioperative and Radiological Outcomes

Parameter	Robotic TKA (n=40)	Conventional TKA (n=40)	p-value
Mean Operative Time (minutes)	108 ± 12	92 ± 10	0.001*
Mean Blood Loss (ml)	310 ± 55	380 ± 70	0.002*
Mechanical Axis Deviation (°)	1.2 ± 0.9	2.8 ± 1.5	0.001*

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Outliers (>3° alignment error)	2 (5%)	8 (20%)	0.04*
Length of Hospital Stay (days)	4.8 ± 1.2	5.6 ± 1.5	0.03*
Intraoperative Complications	1 (2.5%)	3 (7.5%)	0.30

*Statistically significant

Robotic group showed significantly better alignment accuracy and lower blood loss but longer operative time.

Table 3. Functional and Clinical Outcomes at 1 Year

Outcome Measure	Robotic TKA (n=40)	Conventional TKA (n=40)	p-value
6-month KSS	82.6 ± 6.4	78.9 ± 7.1	0.01*
1-year KSS	89.4 ± 5.8	84.7 ± 6.6	0.003*
1-year WOMAC	14.8 ± 5.2	18.6 ± 6.4	0.01*
1-year ROM (°)	122.4 ± 8.6	116.8 ± 9.3	0.004*
Anterior Knee Pain (%)	3 (7.5%)	8 (20%)	0.09
Revision within 1 year	0	1 (2.5%)	0.31
Patient Satisfaction (%)	92.5%	82.5%	0.08

Robotic TKA demonstrated superior functional scores and better ROM at 1 year.

Figure 1: Comparison of Functional and Peri-Operative Outcomes
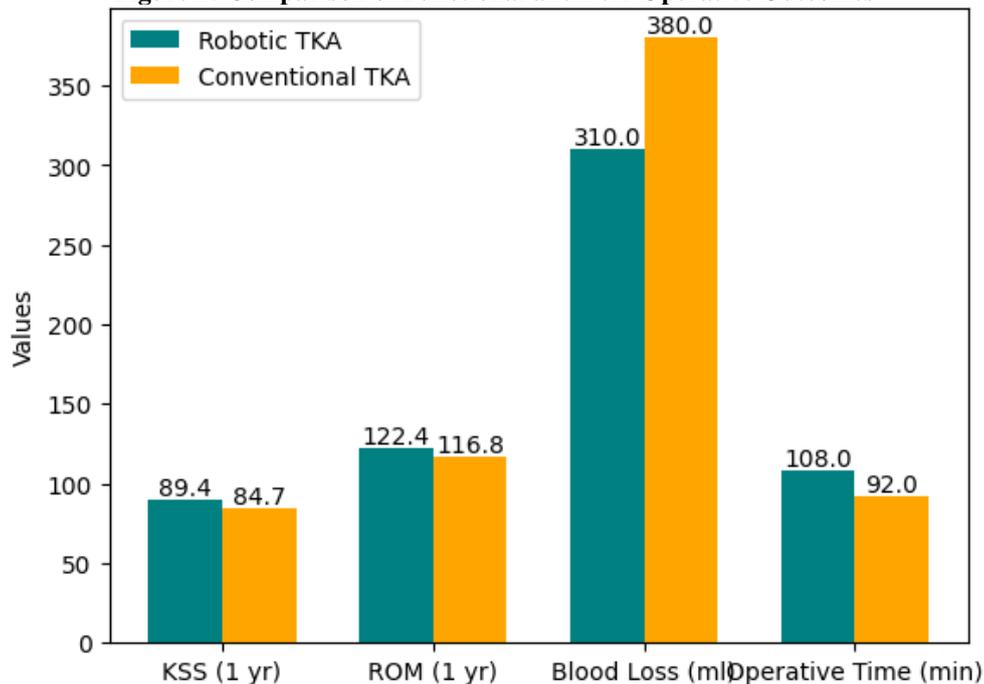
DISCUSSION

In the present prospective study involving 80 patients (40 robotic-assisted TKA and 40 conventional TKA), robotic-assisted surgery demonstrated superior radiological precision and improved functional outcomes at one year, although at the cost of longer operative time. The mean 1-year Knee Society Score (KSS) was significantly higher in the robotic group (89.4 ± 5.8) compared to the conventional group (84.7 ± 6.6; p = 0.003). Similarly, the 1-year WOMAC score was lower in the robotic group (14.8 ± 5.2 vs 18.6 ± 6.4; p = 0.01), indicating better functional performance.

These findings are comparable to the prospective cohort study by **Kayani et al. [9]**, who reported significantly improved early functional recovery and faster discharge in robotic TKA patients. In their study, robotic-assisted TKA patients demonstrated superior early functional scores and shorter hospital stay, which aligns with the reduced hospital stay observed in the present study (4.8 ± 1.2 days vs 5.6 ± 1.5 days; p = 0.03).

Similarly, **Marchand et al. [10]** reported improved 1-year patient-reported outcomes in robotic-assisted TKA, including better functional subscales compared to manual techniques. The magnitude of functional improvement in their study was comparable to the 4.7-point KSS difference observed in the present cohort.

From an alignment perspective, the present study showed significantly lower mechanical axis deviation in the robotic group ($1.2 \pm 0.9°$) compared to the conventional group ($2.8 \pm 1.5°$; $p = 0.001$), with fewer alignment outliers (5% vs 20%; $p = 0.04$). This closely corresponds with the meta-analysis by **Agarwal et al. [11]**, which demonstrated significantly improved alignment accuracy and reduced outliers with robotic systems. Likewise, the randomized controlled trial meta-analysis by **Alrajeb et al. [12]** concluded that robotic-assisted TKA significantly improves postoperative mechanical alignment while clinical outcomes show moderate but consistent advantage.

Operative time was significantly longer in the robotic group in this study (108 ± 12 minutes vs 92 ± 10 minutes; $p = 0.001$), a trend similarly reported by **St Mart & Goh [13]**, who highlighted prolonged operative duration and learning curve as limitations of robotic systems. The systematic review by **Fozo et al. [15]** also noted longer surgical times in robotic procedures, despite improved alignment metrics.

With regard to complication rates, no revision occurred in the robotic group compared to one revision (2.5%) in the conventional group during one-year follow-up. Although not statistically significant, this trend mirrors findings from the matched analysis by **Samuel et al. [14]**, where complication rates were comparable between groups.

The improved mechanical axis accuracy and reduced variability seen in this study also correlate with the findings of **Fu et al. [16]**, who demonstrated superior reproducibility of component placement in robotic-assisted TKA. Furthermore, improved precision in implant positioning reported by **Bourgeault-Gagnon et al. [17]** supports the lower alignment deviation observed in this cohort.

Recent reviews such as **Pipino et al. [18]** have emphasized that while radiological superiority of robotic TKA is well established, improvements in patient-reported outcomes are moderate but clinically meaningful in selected populations. The present study supports this observation, demonstrating statistically significant but not dramatic functional superiority at one year.

Overall, the findings of this study reinforce the growing body of evidence that robotic-assisted TKA enhances alignment precision and yields modest but statistically significant improvements in functional outcomes at one year. However, increased operative time remains a consistent trade-off. The results suggest that while robotic systems improve surgical reproducibility and early recovery parameters, long-term clinical superiority requires further large-scale randomized evaluation.

CONCLUSION
This prospective comparative study demonstrated that robotic-assisted total knee arthroplasty resulted in superior mechanical alignment accuracy, reduced intraoperative blood loss, shorter hospital stay, and significantly improved functional outcomes at one year compared with conventional total knee arthroplasty. Although operative time was longer in the robotic group, the improvements in Knee Society Score, WOMAC score, and postoperative range of motion indicate meaningful clinical benefits. The findings suggest that robotic-assisted TKA enhances surgical precision and contributes to better early functional recovery, supporting its role as an advanced surgical modality in selected patients.

LIMITATIONS
The study was conducted at a single center with a relatively small sample size of 80 patients, which may limit generalizability. The follow-up duration of one year may not be sufficient to assess long-term implant survival, revision rates, and durability of functional improvements. Surgeon experience and learning curve associated with robotic systems may have influenced operative time and outcomes. Additionally, cost analysis and patient-reported satisfaction beyond standardized scoring systems were not comprehensively evaluated.

RECOMMENDATIONS
Future multicentric randomized controlled trials with larger sample sizes and longer follow-up are recommended to evaluate long-term survivorship and cost-effectiveness of robotic-assisted TKA. Comparative studies incorporating quality-of-life assessments and detailed economic analysis would provide broader insight into its clinical value. Adoption of robotic systems should be accompanied by structured training programs to overcome learning curve challenges. Integration of precision technology with patient-specific planning may further optimize outcomes and enhance the overall quality of knee arthroplasty care.

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