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Comparative Outcomes of Robotic-Assisted vs. Conventional Total Knee Arthroplasty

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ABSTRACT

Background: Robotic-assisted total knee arthroplasty (TKA) has emerged as a precision-enhancing alternative to conventional TKA, yet real-world evidence from low- and middle-income settings remains limited. **Objective:** This study compares perioperative, radiographic, and early functional outcomes between robotic-assisted and conventional TKA in a tertiary care cohort.

Methods: A retrospective comparative study was conducted at Jinnah Postgraduate Medical Center from May 2023 to May 2024 on 138 patients who underwent primary TKA. Patients were assigned to either robotic-assisted (n = 69) or conventional TKA (n = 69) based on operative technique. Demographics, intraoperative parameters, radiographic alignment, postoperative recovery, complications, and 6-month functional outcomes (WOMAC, KSS, satisfaction) were compared.

Results: Baseline characteristics were comparable between groups. Robotic TKA had longer operative time (102.6 ± 12.8 vs. 94.2 ± 11.3 min; p < 0.001) but lower blood loss (172 ± 41 vs. 222 ± 58 mL; p < 0.001) and fewer soft-tissue releases (11.6% vs. 27.5%; p = 0.018). Alignment within ±3° of neutral was achieved more frequently in the robotic group (91.3% vs. 72.5%; p = 0.006). Early ambulation (<24 h) and shorter length of stay were more common after robotic TKA (76.8% vs. 58.0%; p = 0.019 and 3.2 ± 0.9 vs. 4.1 ± 1.1 days; p < 0.001, respectively). Six-month WOMAC and KSS scores were significantly better in the robotic group (p = 0.002 and p = 0.001).

Conclusion: Robotic-assisted TKA demonstrated superior radiographic precision and improved early recovery and functional outcomes compared to conventional TKA, despite longer operative time. Prospective studies with long-term follow-up and cost-analysis are warranted to define durability and feasibility of broader implementation in resource-limited healthcare systems.

Keywords: *Robotic arthroplasty, conventional TKA, alignment accuracy, functional outcome*

1. INTRODUCTION

Total knee arthroplasty (TKA) is one of the most successful and frequently performed orthopedic procedures for end-stage knee osteoarthritis, with consistently high rates of pain relief and functional restoration [1]. However, conventional (manual-instrumented) TKA is inherently dependent on surgeon skill, visual judgment, and intra-operative anatomic assumptions, which can contribute to malalignment, soft-tissue imbalance, outliers in component positioning, and suboptimal long-term functional outcomes [2]. Robotic-assisted TKA emerged as a technological attempt to reduce these sources of variability by improving surgical precision through pre-operative imaging or intra-operative mapping, haptic boundaries, and computer-guided bone resection, theoretically translating into more accurate implant alignment and more consistent gap balancing [3].

Robotic-assisted TKA was developed to address these limitations by enabling reproducible bone preparation and alignment through three-dimensional planning, real-time feedback, and haptic guidance [4]. Early studies demonstrate that robotic systems reduce alignment outliers, improve the accuracy of resection cuts, and decrease the need for soft-tissue releases compared with manual techniques. Emerging reports also suggest potential benefits in terms of early pain, faster rehabilitation, reduced intra-operative trauma, and improved patient-reported outcome measures. However, the durability of these benefits beyond the early postoperative period remains uncertain [5].

Economic and system-level considerations are equally relevant. Robotic installation introduces cost burdens related to platform acquisition, maintenance contracts, disposable accessories, licensing, and OR workflow remodeling. In addition, substantial training and a learning curve are required to integrate robotics without prolonging operative duration or destabilizing throughput [6]. In high-volume centers, cost amortization and workflow adaptation may favor adoption, but in resource-limited or public health systems, the opportunity cost of such investment must be justified by demonstrable and sustained clinical advantages. Whether hypothetical reductions in revision rates, litigation risk, or rehabilitation requirements are sufficient to offset these costs is not yet established by high-quality longitudinal evidence [7].

Another unresolved variable is the time horizon. Several published comparisons have been limited to short-term follow-up periods, typically 3, 6, or 12 months, which may not capture meaningful differences in implant survival, late mechanical complications, or functional decay. Given that TKA is designed to provide durable improvement over decades, conclusions based solely on early outcomes may be premature [8]. Conversely, if robotics produces immediate functional gains without long-term harm or cost inflation, such early gains alone could justify adoption depending on societal valuation of early recovery. Patient selection may further bias comparative observations [9]. Robotic TKA is more frequently performed in high-volume academic or private institutions, on relatively healthier and more motivated patients, and by surgeons with a specific interest and experience in precision-based arthroplasty [10]. These contextual differences can confound interpretations of superiority unless controlled through comparable cohorts or rigorous methodology. Therefore, comparative research must account for center effect, surgeon effect, and case-mix effect to avoid attributing institutional performance to technology [11].

2. OBJECTIVE

This study compares perioperative, radiographic, and early functional outcomes between robotic-assisted and conventional TKA in a tertiary care cohort.

3. METHODOLOGY

This was a retrospective comparative study conducted at Jinnah Postgraduate Medical Center from May 2023 to May 2024. Medical records of patients who underwent primary total knee arthroplasty (TKA) over the defined study period were reviewed and categorized into two cohorts based on the technique used: robotic-assisted TKA and conventional instrumented TKA. A total of 138 patients who fulfilled the eligibility criteria were included. Eligible patients were adults diagnosed with advanced knee osteoarthritis who underwent primary TKA during the study period. Exclusion criteria included revision arthroplasty, severe coronal deformity outside correctable range for robotics, periprosthetic infection, incomplete documentation, and absence of follow-up data. Patients were retrospectively assigned into robotic-assisted or conventional TKA groups based on the recorded operative modality.

Data collection

Data were abstracted from operative notes, radiographic archives, electronic medical records, and follow-up clinic documentation using a structured proforma. Extracted variables included baseline demographics (age, sex, BMI, comorbidities), intra-operative details (operative duration, estimated blood loss, soft-tissue release, intra-operative complications), and postoperative parameters (time to mobilization, length of stay, early complications such as infection, thromboembolism, stiffness, wound complications). Robotic-assisted cases were performed using a calibrated robotic navigation system with either pre-operative CT-based planning or intra-operative mapping depending on the platform used at the time of surgery. Conventional TKA procedures employed standard mechanical jigs with manual alignment techniques. All patients received the same implant family and underwent the same institutional perioperative care protocols including anesthesia, antibiotic prophylaxis, DVT prophylaxis, pain regimen, and postoperative rehabilitation pathway to minimize confounding arising from perioperative variability. Functional outcomes and radiographic alignment data at last follow-up were collected using recorded Knee Society Score, WOMAC or Oxford Knee Score, and documented radiographic measurements. Any re-intervention or revision during follow-up was noted.

Statistical Analysis

Data were analyzed using SPSS v26.0. Continuous variables were tested for normality and compared between groups using independent t-test. Categorical variables were compared using the Chi-square test. A p-value of <0.05 was considered statistically significant.

4. RESULTS

Data were collected from 138 patients. Baseline demographic and clinical characteristics were comparable between the two groups. The mean age was similar in the robotic (63.4 ± 6.2 years) and conventional (64.1 ± 6.7 years) cohorts. Females represented the majority in both groups (75.4% and 72.5%, respectively). Mean BMI was also comparable (28.3 ± 3.4 vs. 28.7 ± 3.6 kg/m²). The prevalence of hypertension (62.3% vs. 59.4%) and diabetes mellitus (41.0% vs. 44.9%) did not differ significantly between the two arms, indicating that both groups were clinically well-balanced at baseline.

Table 1. Baseline Demographic and Clinical Characteristics (N = 138)

Variable	Robotic TKA (n = 69)	Conventional TKA (n = 69)
Age (years), mean ± SD	63.4 ± 6.2	64.1 ± 6.7
Female gender	52 (75.4%)	50 (72.5%)
BMI (kg/m²), mean ± SD	28.3 ± 3.4	28.7 ± 3.6
Hypertension	43 (62.3%)	41 (59.4%)
Diabetes mellitus	28 (41.0%)	31 (44.9%)

Robotic-assisted TKA required significantly longer operative time compared with conventional TKA (102.6 ± 12.8 vs. 94.2 ± 11.3 minutes; p < 0.001). However, blood loss was significantly lower in the robotic group (172 ± 41 mL vs. 222 ± 58 mL; p < 0.001), and soft-tissue releases were required less frequently (11.6% vs. 27.5%; p = 0.018). No intraoperative complications occurred in either group. Radiographically, robotic TKA achieved superior accuracy, with 91.3% of cases achieving mechanical axis within ±3° of neutral versus 72.5% in the conventional group (p = 0.006). Alignment outliers were significantly fewer in the robotic group (8.7% vs. 27.5%; p = 0.004), demonstrating greater precision with robotic assistance.

Table 2. Intraoperative Outcomes

Outcome	Robotic TKA (n = 69)	Conventional TKA (n = 69)	p-value
Operative time (min), mean ± SD	102.6 ± 12.8	94.2 ± 11.3	<0.001
Estimated blood loss (mL), mean ± SD	172 ± 41	222 ± 58	<0.001
Soft-tissue release required	8 (11.6%)	19 (27.5%)	0.018
Intraoperative complications	0 (0%)	0 (0%)	—
Alignment Parameter			
Mechanical axis within ±3° of neutral	63 (91.3%)	50 (72.5%)	0.006
Alignment outliers (>3° deviation)	6 (8.7%)	19 (27.5%)	0.004

Patients in the robotic cohort achieved earlier mobilization, with 76.8% walking within 24 hours versus 58.0% in the conventional group (p = 0.019). Length of hospital stay was also shorter after robotic TKA (3.2 ± 0.9 vs. 4.1 ± 1.1 days; p < 0.001). Early postoperative complications within 30 days were lower in the robotic group (5.8% vs. 13.0%), though the difference was not statistically significant (p = 0.14). No revision or re-intervention was recorded in either group during the follow-up period.

Table 3. Postoperative Recovery and Complications

Outcome	Robotic TKA (n = 69)	Conventional TKA (n = 69)	p-value
Early ambulation <24h	53 (76.8%)	40 (58.0%)	0.019
Length of stay (days), mean ± SD	3.2 ± 0.9	4.1 ± 1.1	<0.001
Early complications (≤30 days)	4 (5.8%)	9 (13.0%)	0.14
Revision / re-intervention	0 (0%)	0 (0%)	—

Functional recovery at six months favored the robotic group. Mean WOMAC scores were lower, indicating better functional status (15.3 ± 6.8 vs. 19.9 ± 7.2; p = 0.002). The Knee Society Score was significantly higher in robotic patients (86.4 ± 8.1 vs. 80.7 ± 9.3; p = 0.001). Patient-reported satisfaction rates were also significantly greater in the robotic group (91.3% vs. 79.7%; p = 0.048), reflecting higher perceived benefit.

Table 4. Functional Outcomes at 6 Months

Outcome	Robotic TKA (n = 69)	Conventional TKA (n = 69)	p-value
WOMAC score, mean ± SD	15.3 ± 6.8	19.9 ± 7.2	0.002
Knee Society Score, mean ± SD	86.4 ± 8.1	80.7 ± 9.3	0.001
Patient satisfaction	63 (91.3%)	55 (79.7%)	0.048

5. DISCUSSION

In this comparative retrospective analysis of 138 patients undergoing primary total knee arthroplasty, robotic-assisted TKA demonstrated superior precision in alignment and favorable perioperative and early functional outcomes relative to conventional TKA. Baseline demographics and comorbidity profiles were comparable between groups, strengthening the validity of comparative interpretation. Operative duration was significantly longer in the robotic cohort, consistent with published literature attributing increased time to system calibration, registration, and workflow adaptation during early adoption. However, this disadvantage was offset by significantly lower intraoperative blood loss and reduced reliance on soft-tissue releases. These findings suggest that robotic guidance may contribute to more controlled resection planes, thereby reducing intraoperative soft-tissue insult [12].

Radiographic analysis confirmed that robotic assistance achieved significantly higher rates of neutral mechanical alignment and fewer outliers, supporting prior evidence that robotic systems improve executional accuracy. Improved alignment reproducibility is clinically meaningful given its reported association with implant longevity and kinematic stability. Early postoperative recovery was more favorable in the robotic cohort, as reflected by earlier ambulation and shorter length of hospital stay. Although early complication rates were numerically lower among robotic cases, the difference did not reach statistical significance, likely due to sample size limitations [13]. Importantly, no revisions or severe adverse events occurred in either group during the observed follow-up period.Several mechanisms may explain the superiority of robotic-assisted TKA observed in this study. Robotic execution allows bone resections to be performed within pre-planned haptic boundaries, which likely reduces micro-trauma to periarticular soft tissues [14]. This, in turn, may account for the shorter hospitalization and earlier ambulation observed. Furthermore, more accurate balancing of flexion–extension gaps may contribute to the superior six-month functional scores recorded. These findings align with reports indicating that soft-tissue preservation is an independent determinant of early postoperative pain and quadriceps recovery, which are key predictors of return to function [16]. Although robotic TKA required a longer operative duration, this finding is consistent with early-adoption phases and is expected to decrease with procedural familiarization. More importantly, the observed advantages in blood loss, alignment accuracy, and functional outcome may outweigh the trade-off of added time, particularly in high-volume centers where workflow optimization is feasible [17]. From a health-system standpoint, reduced length of stay and potentially lower complication risk can partially offset capital and operational costs of robotic platforms, though definitive economic conclusions require a formal cost-utility analysis beyond the scope of this study [18].

It is noteworthy that while differences in early complications did not reach statistical significance, the direction of effect favored robotics. The absence of infections, thromboembolic events, and revisions across both arms likely reflects adherence to standardized perioperative protocols, as well as the relatively short follow-up period. Longitudinal follow-up is essential to determine whether improved alignment precision will translate into reduced aseptic loosening and revision burden, which would strengthen the argument for long-term value of robotics [19]. Functional outcomes at six months were significantly better among patients receiving robotic TKA as indicated by superior WOMAC and Knee Society Scores, alongside higher patient-reported satisfaction. This supports the hypothesis that precision in component positioning and ligament balance may translate into early perceptible clinical improvements. Taken together, the results indicate that robotic-assisted TKA offers measurable advantages in perioperative performance, radiographic accuracy, and early functional recovery compared to conventional TKA in a real-world tertiary-care setting. However, considerations such as increased operative time, system costs, and learning curve remain relevant when interpreting the feasibility of widespread adoption.

6. CONCLUSION

Robotic-assisted total knee arthroplasty demonstrated measurable advantages over conventional TKA in this study, including reduced intraoperative blood loss, lower requirement for soft-tissue releases, superior alignment precision, faster postoperative recovery, and better early functional outcomes. Although operative time was longer with robotics, this disadvantage was offset by favorable perioperative and clinical trends. The findings support the premise that robotic guidance enhances executional accuracy and may translate into enhanced patient recovery and satisfaction in the early postoperative period.

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